Practical Heat Transfer Technologies on Electronic Components

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Personal Brief Introduction

Name: Joseph F.S. Lee, born in Taiwan in 1952.

Experience: General Manager of Long Win Company for over 20 years

Expert in:

1. Mechanics and manufacture knowledge and technologies in mechanic engineering field.
2. Control field of knowledge and technologies
3. Electronics thermal flow knowledge and technologies
4. System and experimental design and analysis, more than 600 design experiences, and more than USD10,000,000.00 value.
5. More than 2000㎡ laboratory

Long Win's Power

- 2000 m^2 Laboratory for Research
- A New Apparatus monthly born

Practical Heat Transfer Technologies on Electronic Components

Ⅰ. For heat transfer engineering research and analysis on electronic components,

present methods are:

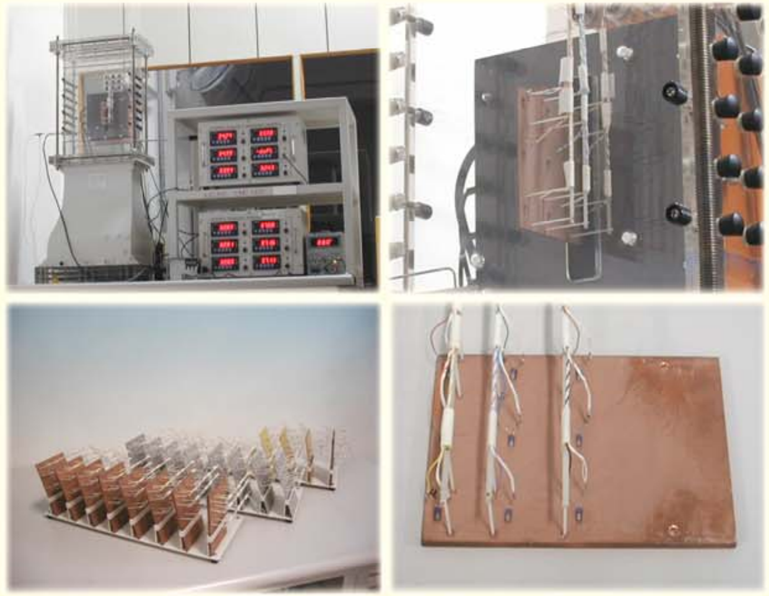
1. theory together with intuition
2. CAE imitation
3. experimental statistics experiences together with theory

Processing Research Items can be for public

A. Plates heat tranfer capability and temperature distribution

1. different material and thickness of plates,
2. different heat power
3. different wind turbulence & velocity
4. single plate
5. multiple parallel plates upon different spacing,
6. by parallel arrangement with air flow.

to build Data Base / Auto Test & Data Acquisition



B. Thermal resistance of fin type heat sink upon fixed area of power source

1. more than 350 kinds of heat sink
2. different material, structure & process
3. different air flow rate
4. different air flow pattern

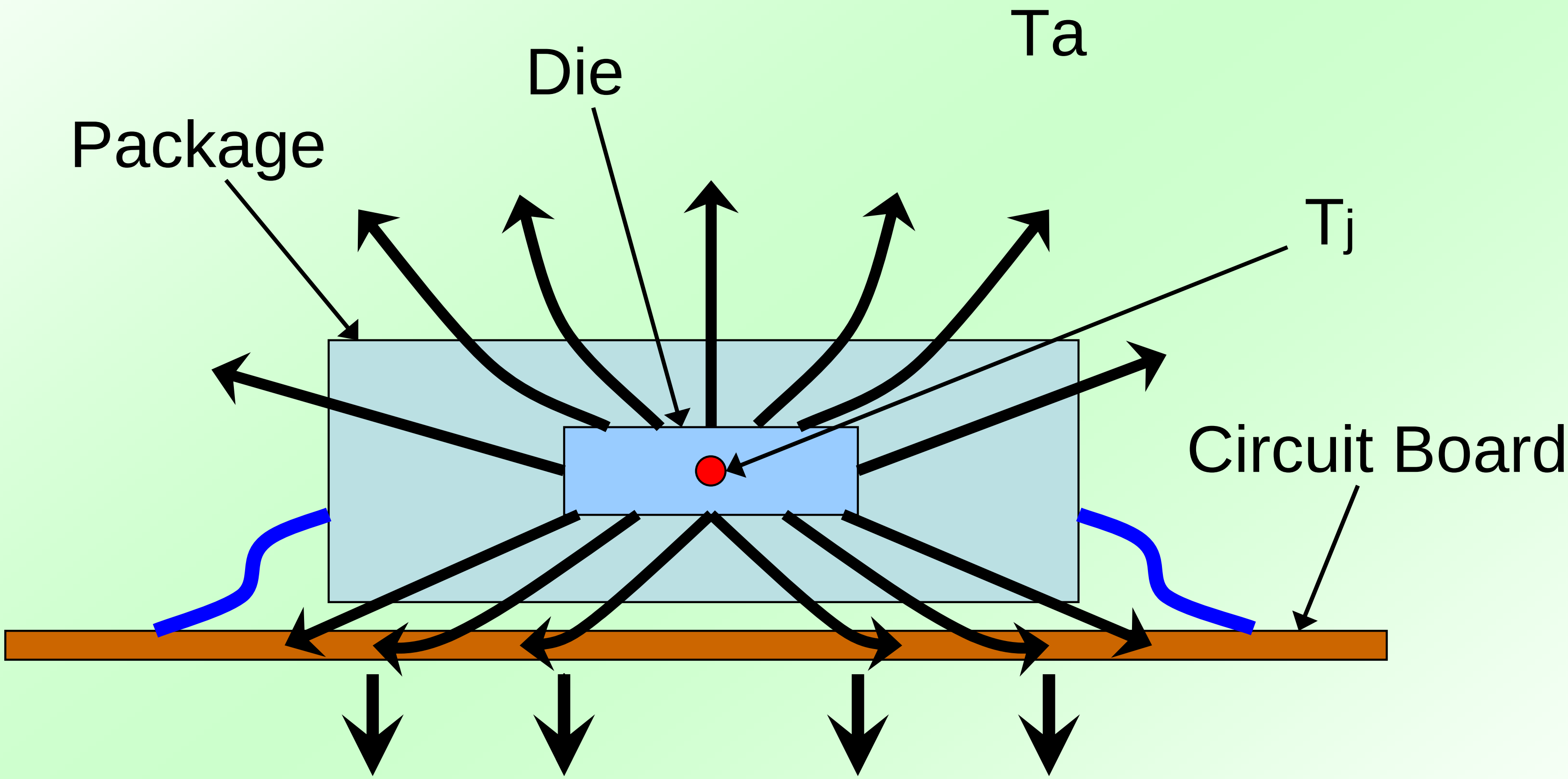
to build Data Base / Auto Test & Data Acquisition

II. **Practical electronics heat transfer knowledge**

1. Basic theoretical idea of thermal conduction on electronic components:
    - A. Conduction
    - B. Convection
    - C. Radiation

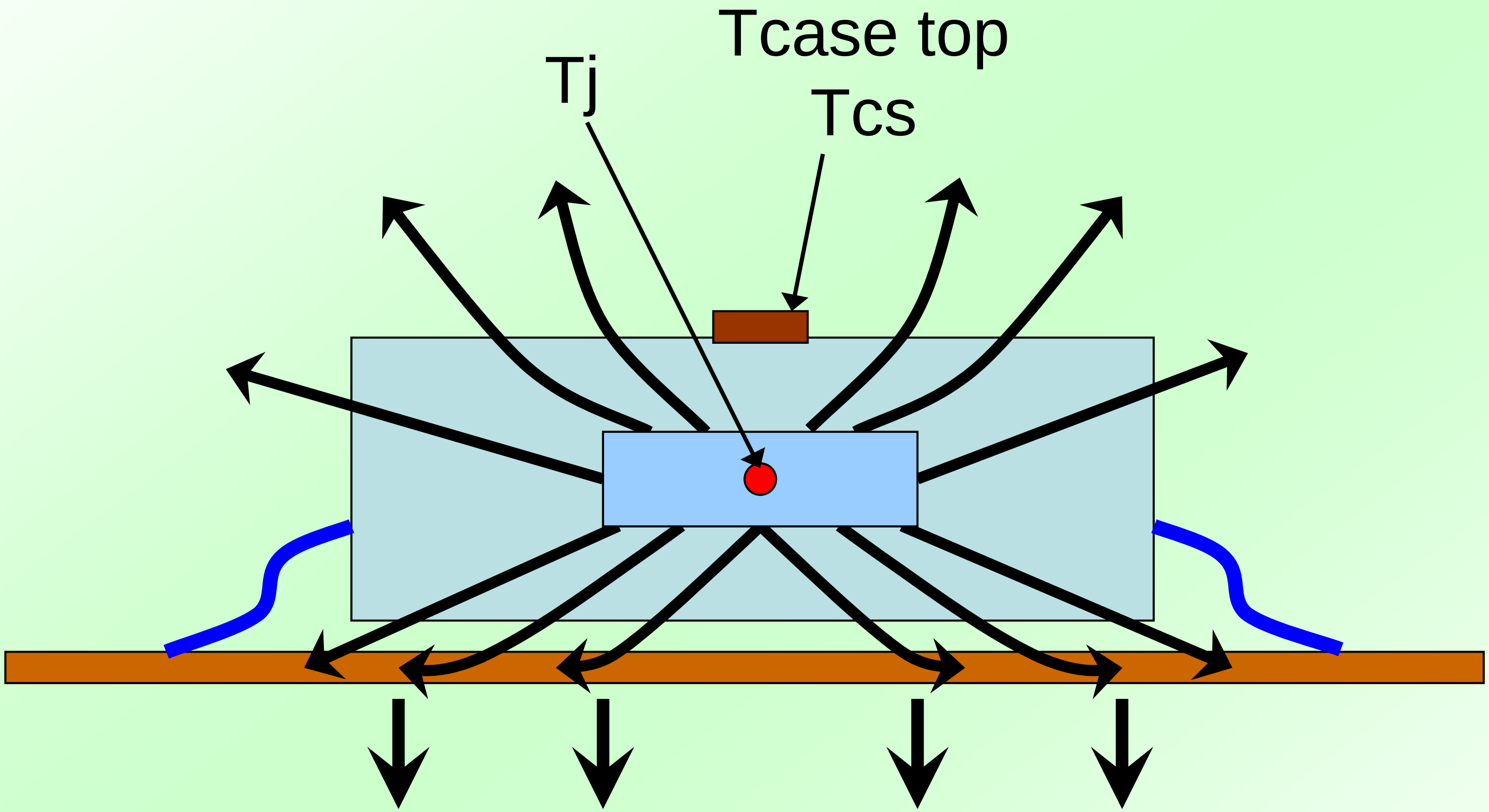
2. Terminology Definition

1. Definition of R_{JA}



$$R_{JA} = \frac{T_J - T_A}{Q}$$

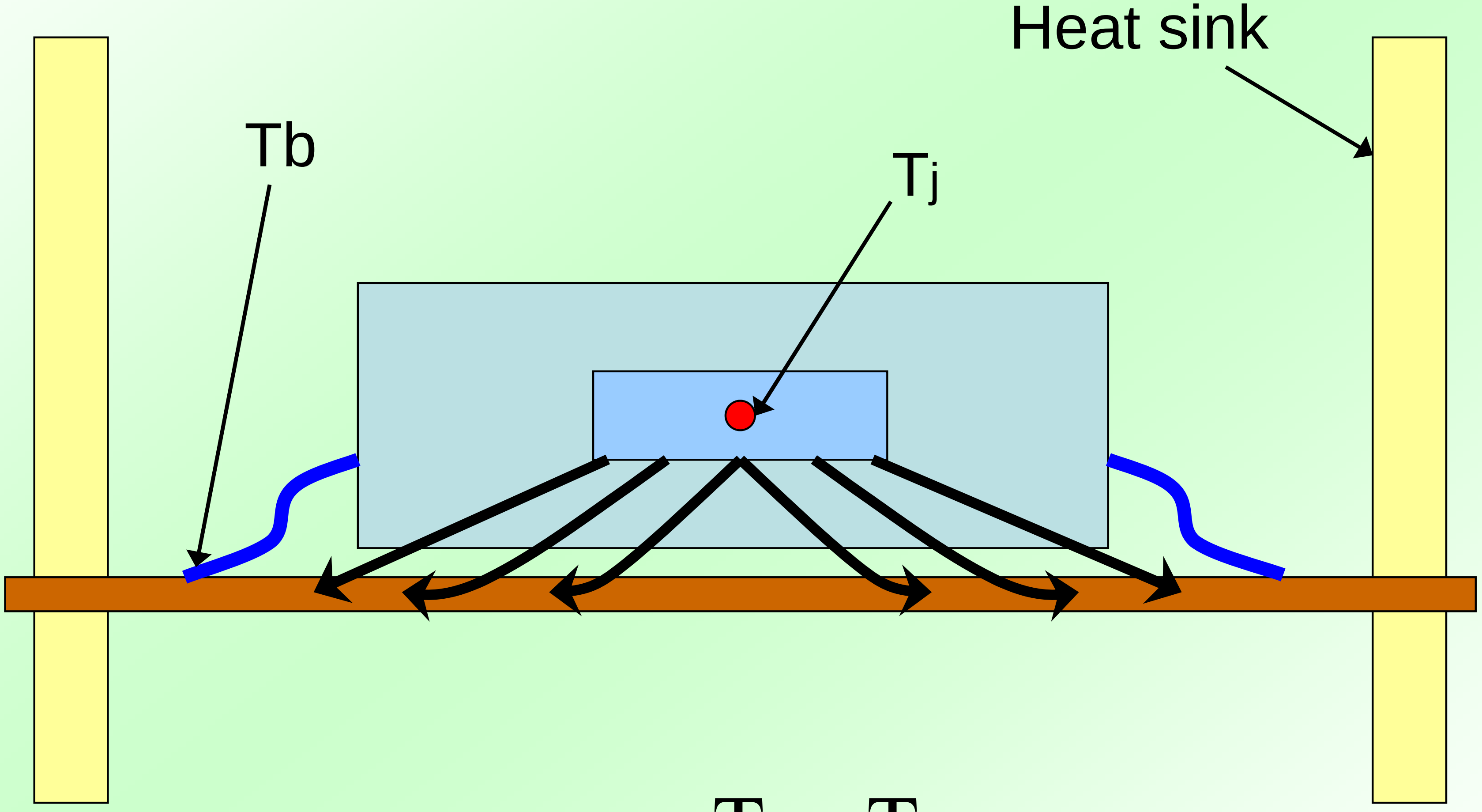
2. Definition of Ψ_{JT}



$$\Psi_{JT} = \frac{T_J - T_{TCS}}{Q}$$

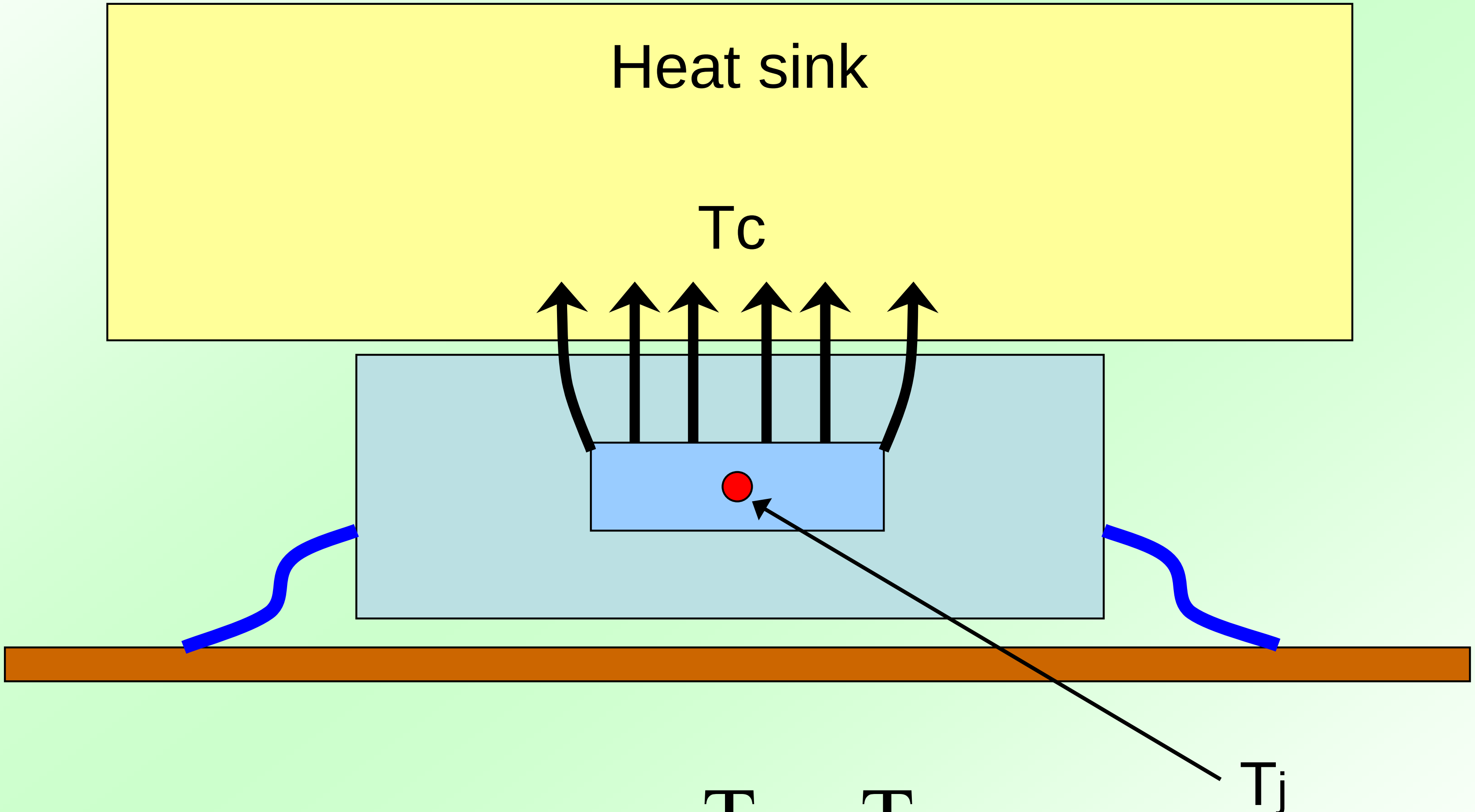
$$R_{JA} = \Psi_{JT} + \Psi_{TA}$$

3. Definition of R_{JB}

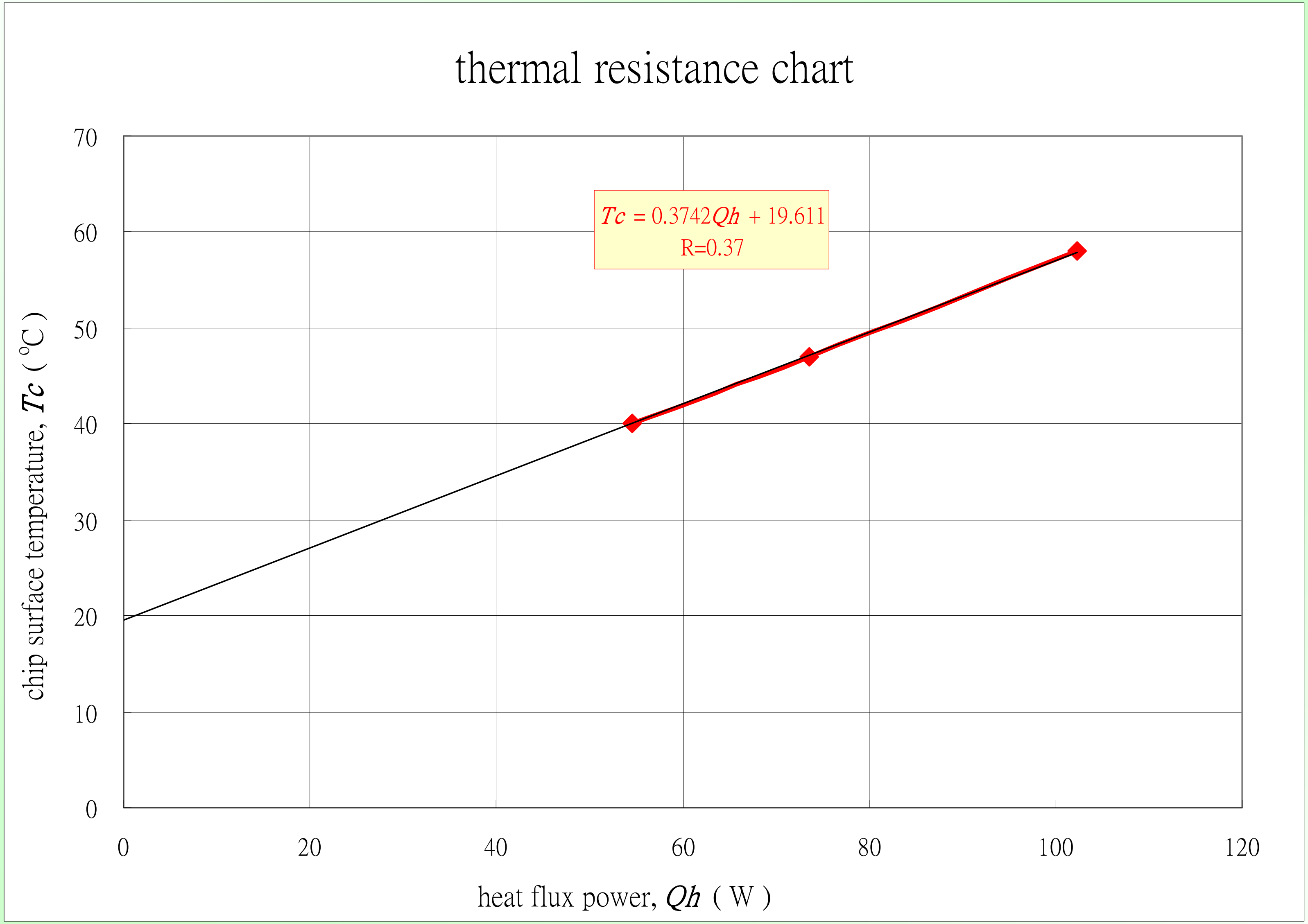


$$R_{JB} = \frac{T_J - T_B}{Q}$$

4. Definition of R_{JC}

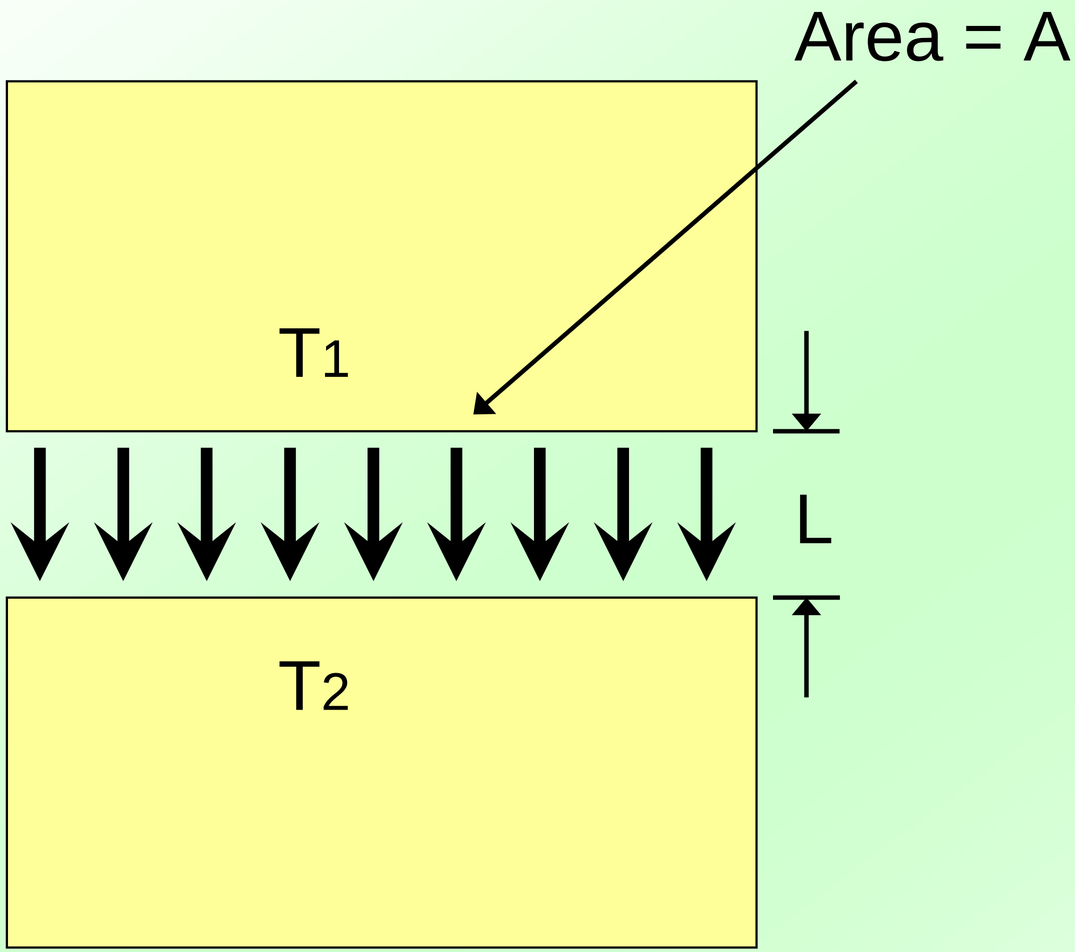


$$R_{JC} = \frac{T_J - T_C}{Q}$$



thermal resistance chart
Tc = 0.3742Qh + 19.611
R=0.37
chip surface temperature, Tc (°C)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
heat flux power, Qh (W)

5. Definition of Thermal Resistivity



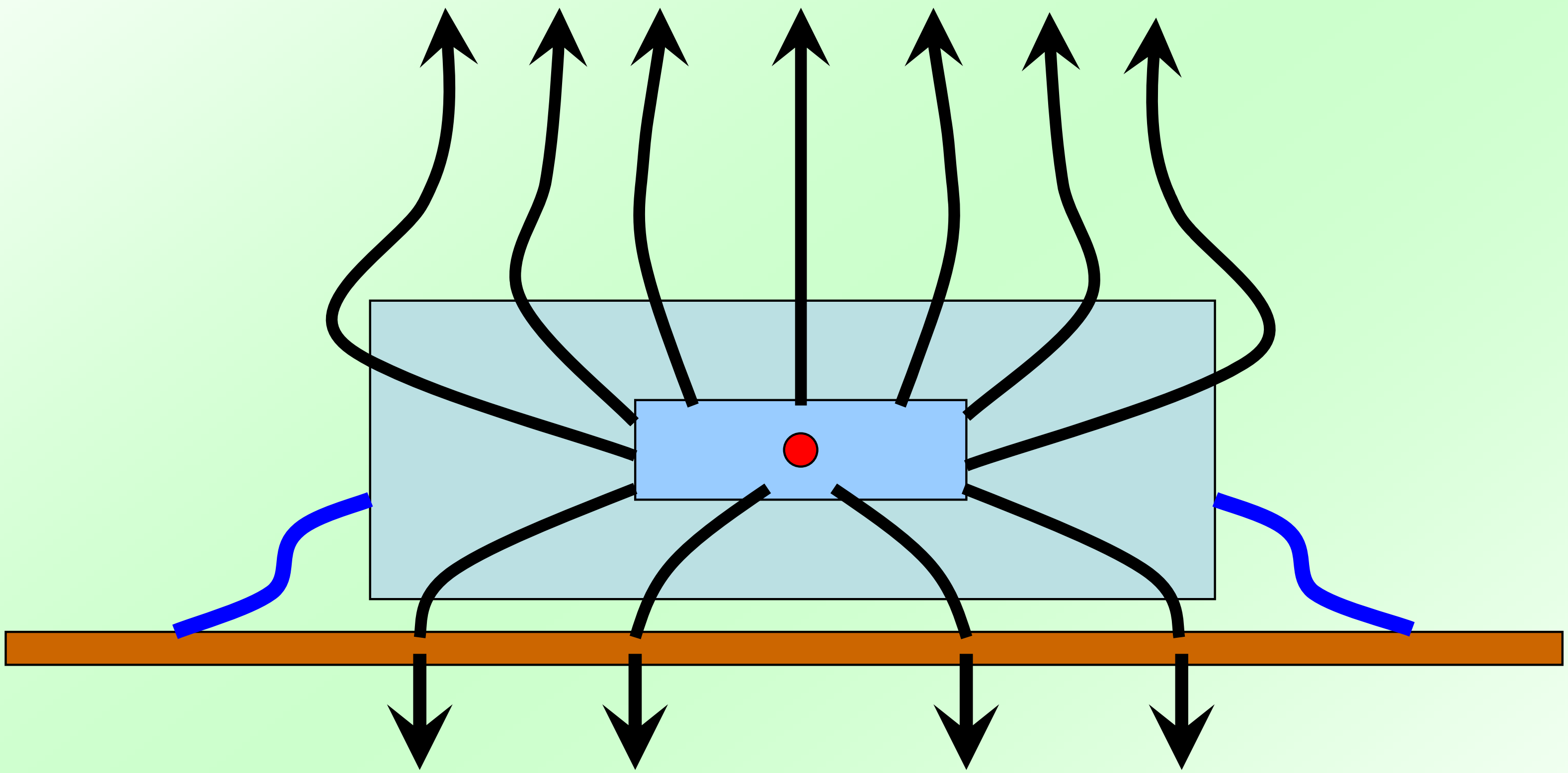
$$R = \frac{T_1 - T_2}{Q} \times \frac{A}{L}$$

$$R = \frac{T_1 - T_2}{Q}$$

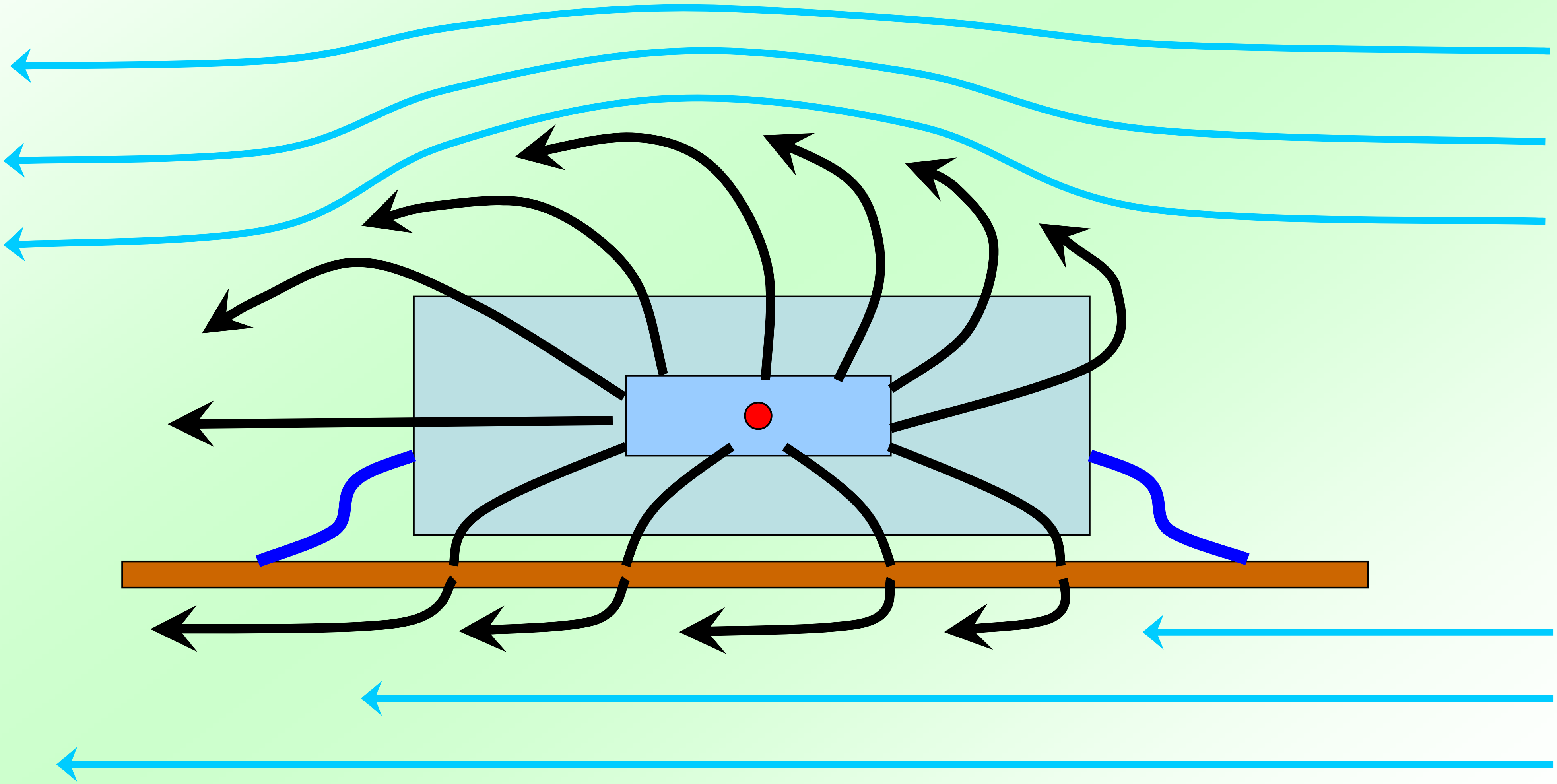
For unit area and
unit thickness

Only for parallel heat flux between parallel isothermal surfaces (simple case)

6. Heat Flow in Still Air



7. Heat Flow in Forced Air



3. To research practical heat transfer problems from basic idea formulas of thermal conduction.

A. Thermal conduction:

a. while conduction element phase is solid state structure, that is solid phase thermal conduction, such as metal heat sink.

b. while conduction element phase is fluid structure, and there is phase change generated, that is air phase thermal conduction, or in forced convection of thermal conduction mode. such as:

(a) heat pipe structure

(b) compressor coolant structure

c. while conduction element phase is liquid state structure, that is fluid phase thermal conduction, such as water cooling structure.

When the heat in high temperature solid state zone is transferred to low temperature solid state zone, the ideal formula is

$$Q = K A \frac{T_h - T_c}{L}$$

Q：transferred heat

K：thermal conduction coefficient of solid state zone of substance

A：effective heat transfer area of solid state zone

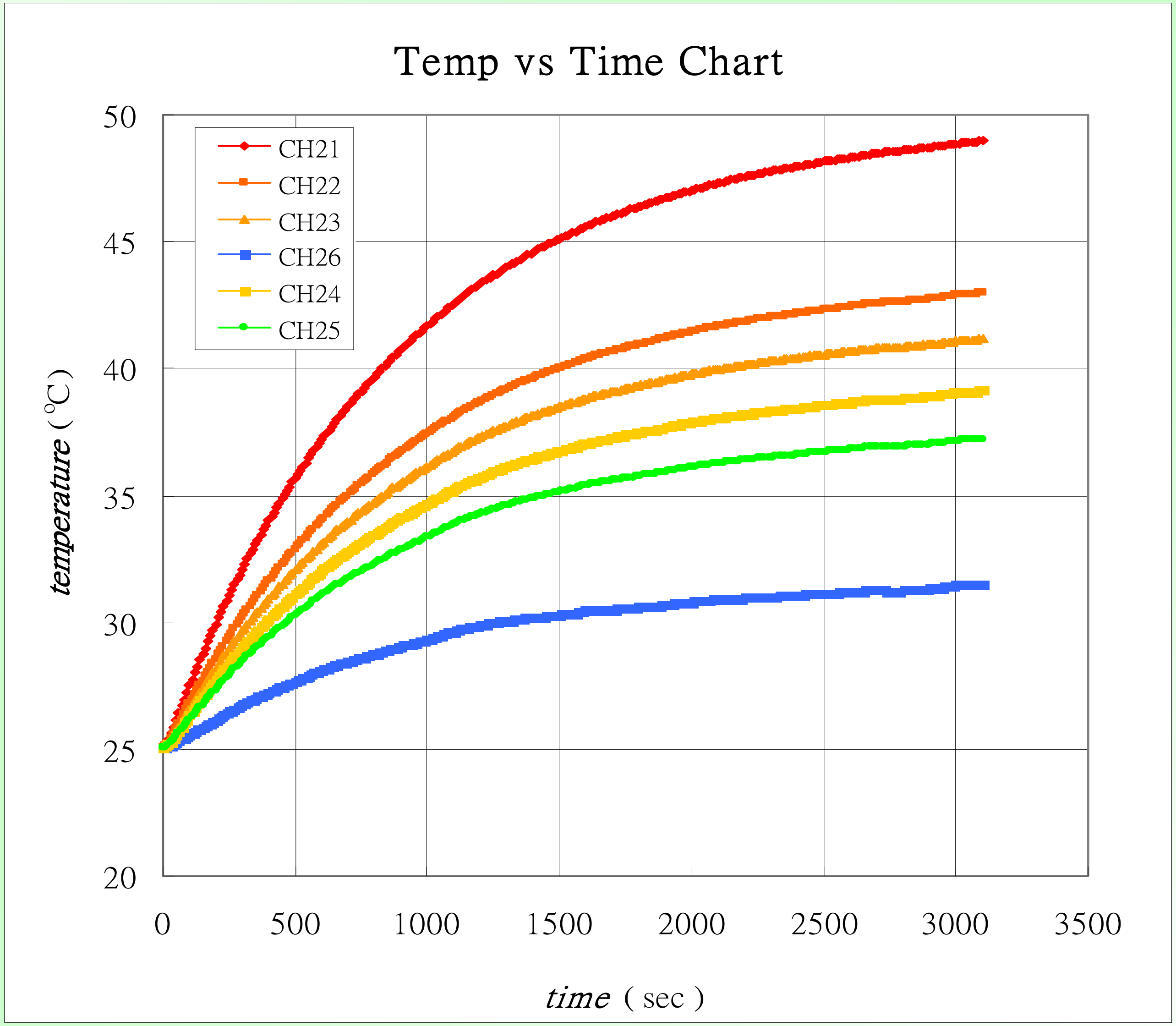
Th：temperature in high-temp solid state zone

Tc：temperature in low-temp solid state zone

L：sampling distance between high and low temperature solid state zones

Bar Material Thermal Conduction Test

Temperature Distribution of Positions on the Axis of the Bar



B. Convection:

a. Natural convection:

while in cooling state without wind, the air movement is served as the result generated by density gradient around the heating element.

b. Forced convection:

while in cooling state with wind, the heat in high temperature solid state zone contacts with the substance in low temperature liquid state or vapor state to generate thermal conduction,

its ideal formula is :

$$Q = \bar{h} A \left(T_s - T_f \right)$$

Q：transferred heat

$\bar{h}$：convection coefficient of thermal conduction

A：effective contact area of high temperature solid state zone and low temperature fluid zone

Ts：contact surface temperature of high temperature solid state zone and fluid level

Tf：the temperature before low temperature fluid does not contact with high temperature solid state zone

While forced convection, the relationship factors between air status and $\bar{h}$ are as following:

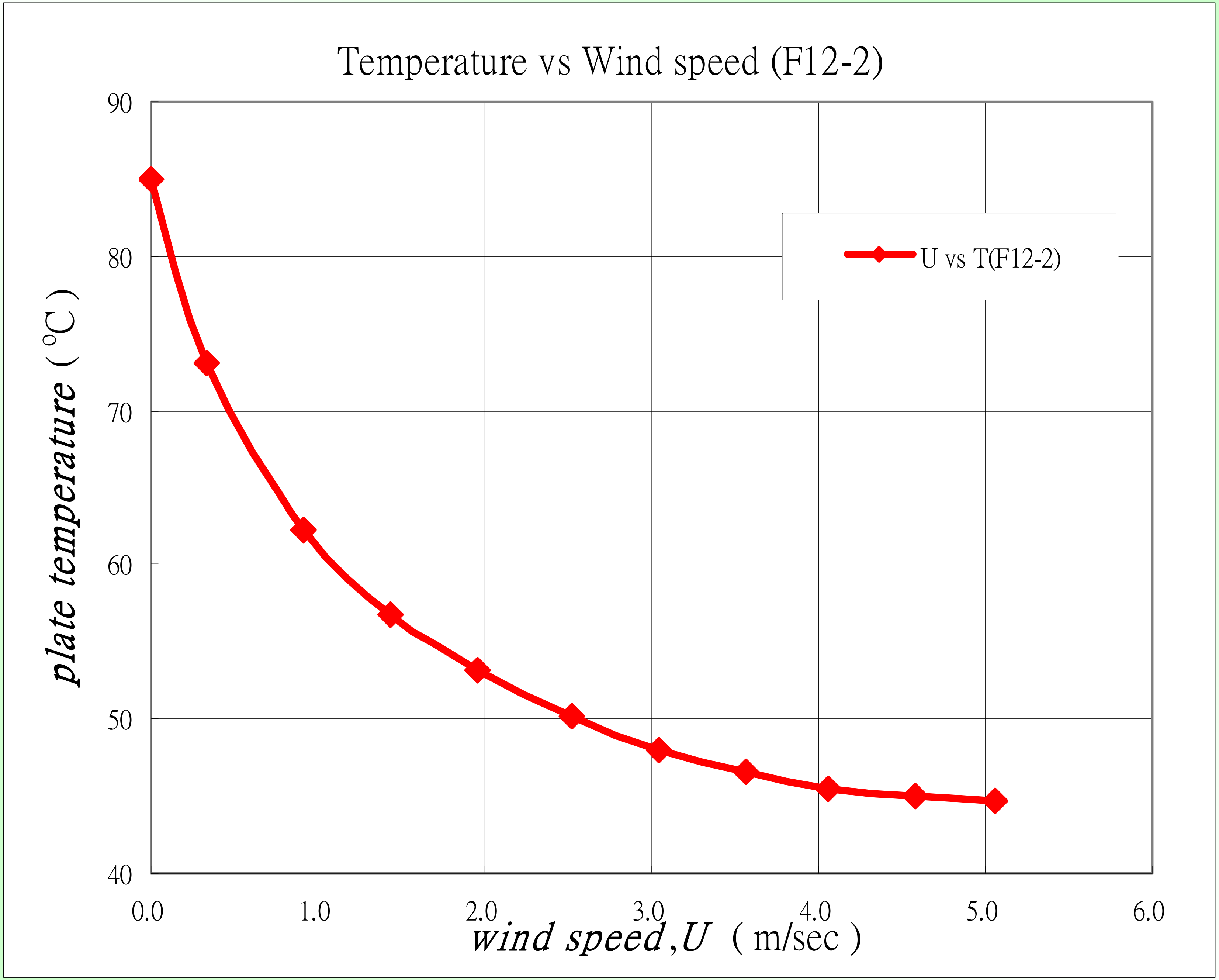
a. air velocity

b. air flow turbulence

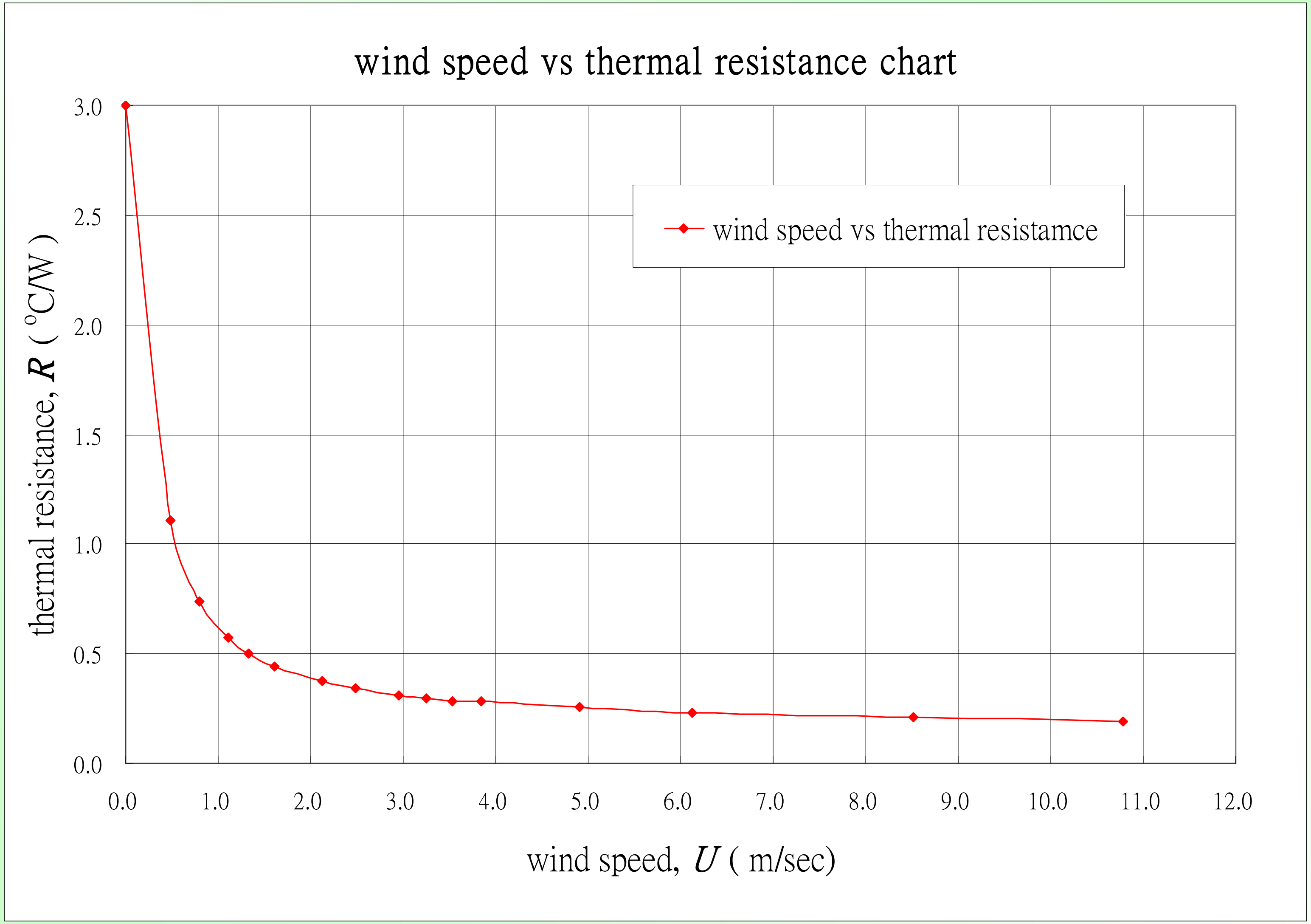
c. surface coarseness of solid state element

d. shape of solid state element

e. distance between two adjacent solid state elements

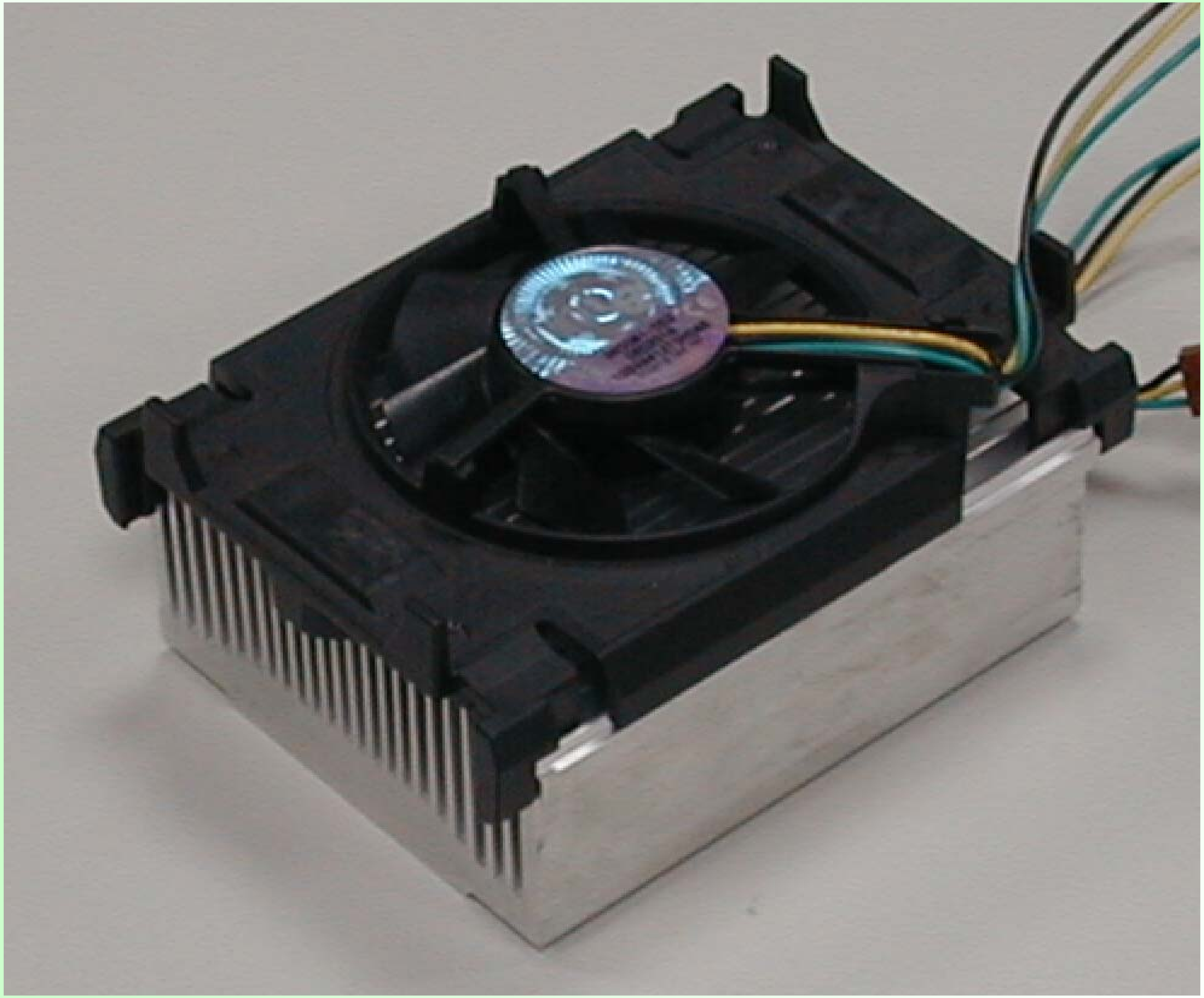


Temperature vs Wind speed (F12-2)
90
80
70
60
50
40
0.0
1.0
2.0
3.0
4.0
5.0
6.0
plate temperature (°C)
wind speed, U (m/sec)
U vs T(F12-2)



wind speed vs thermal resistance chart
wind speed vs thermal resistamce
thermal resistance, R (°C/W)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
wind speed, U (m/sec)

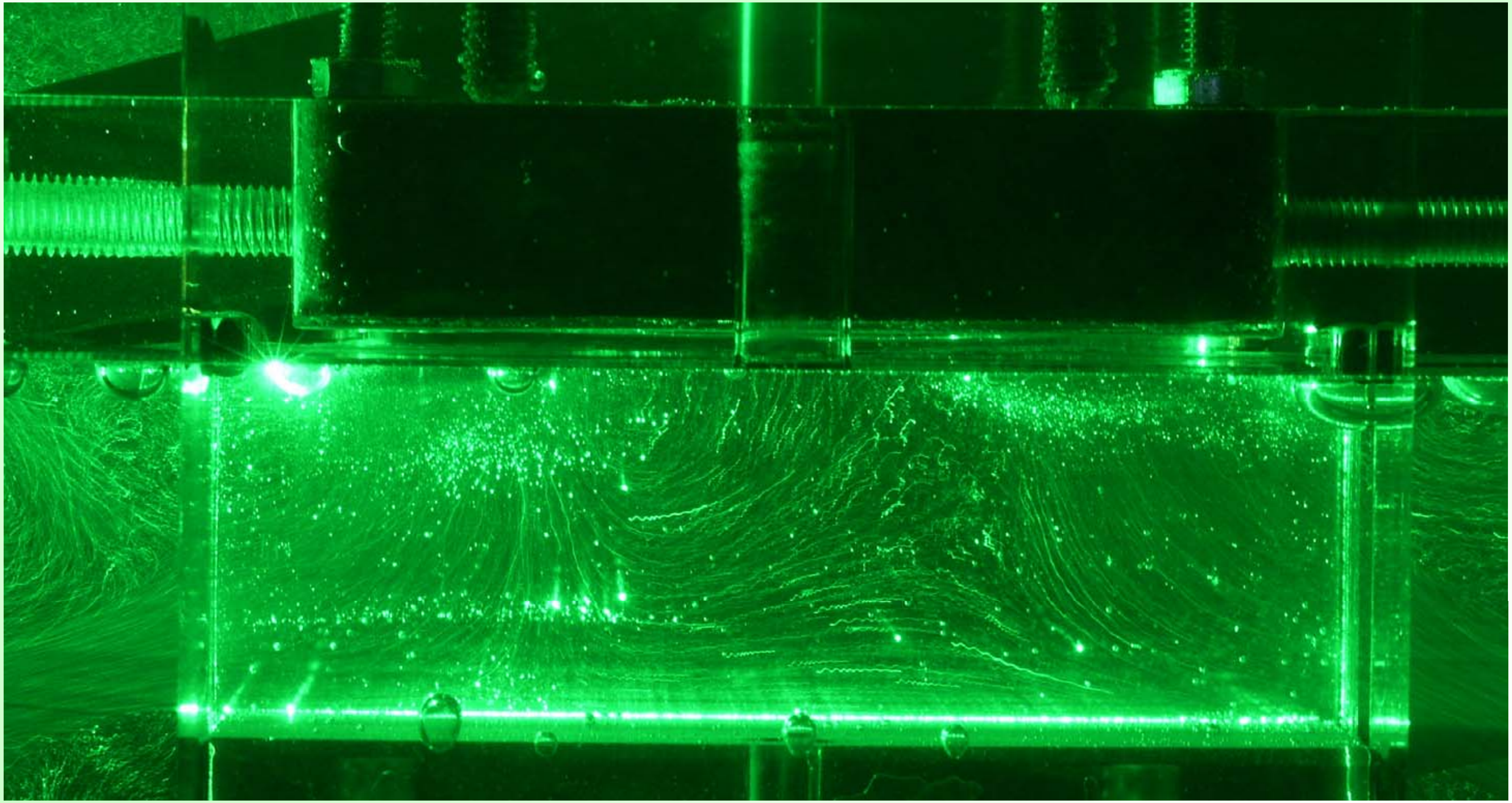
Heatsink for CPU Cooler of Desktop PC

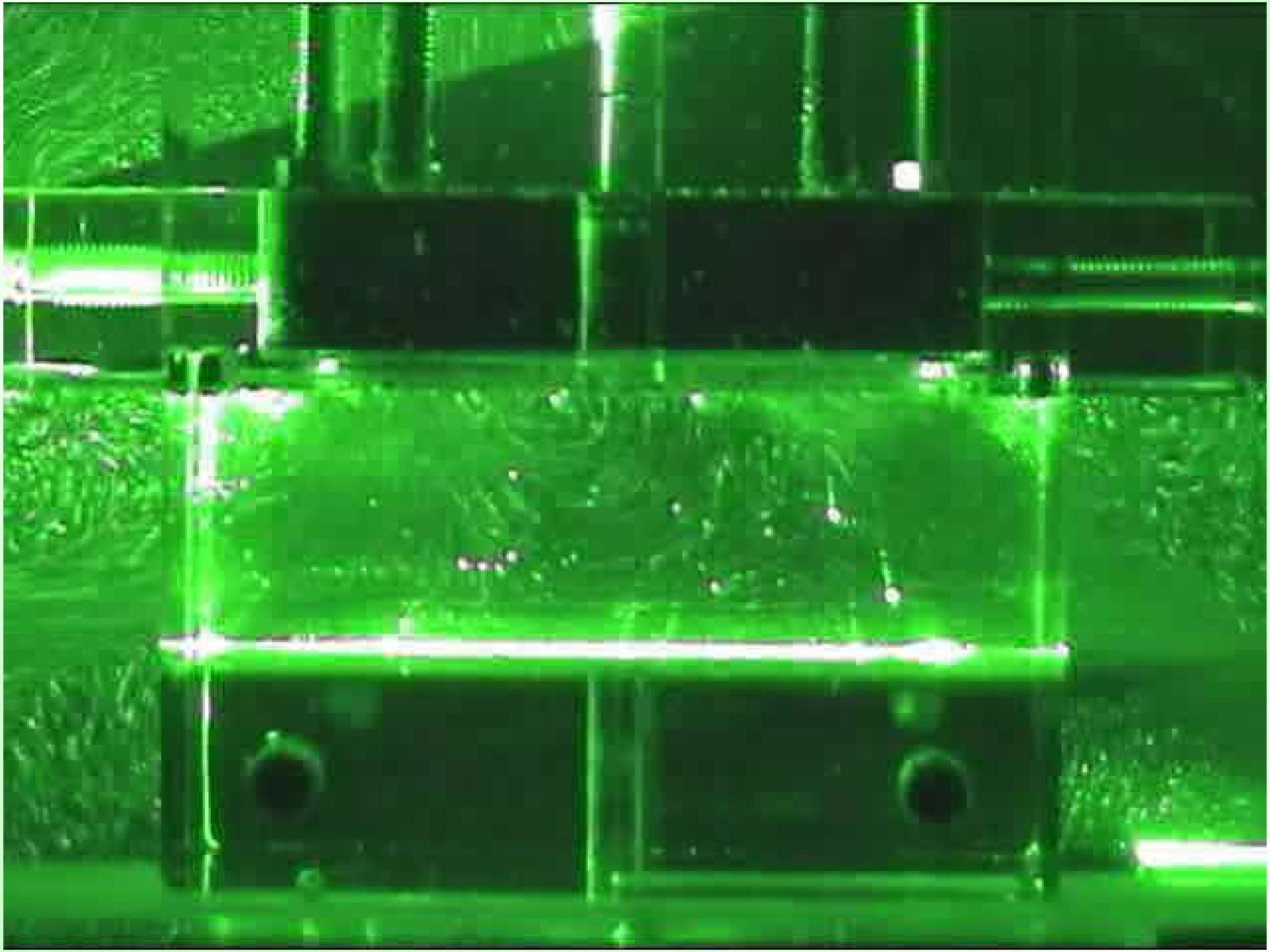


CPU cooler for D/T PC

fin：32 mm high × 76 mm width ×26 gaps

heat sink #9 gap flow field

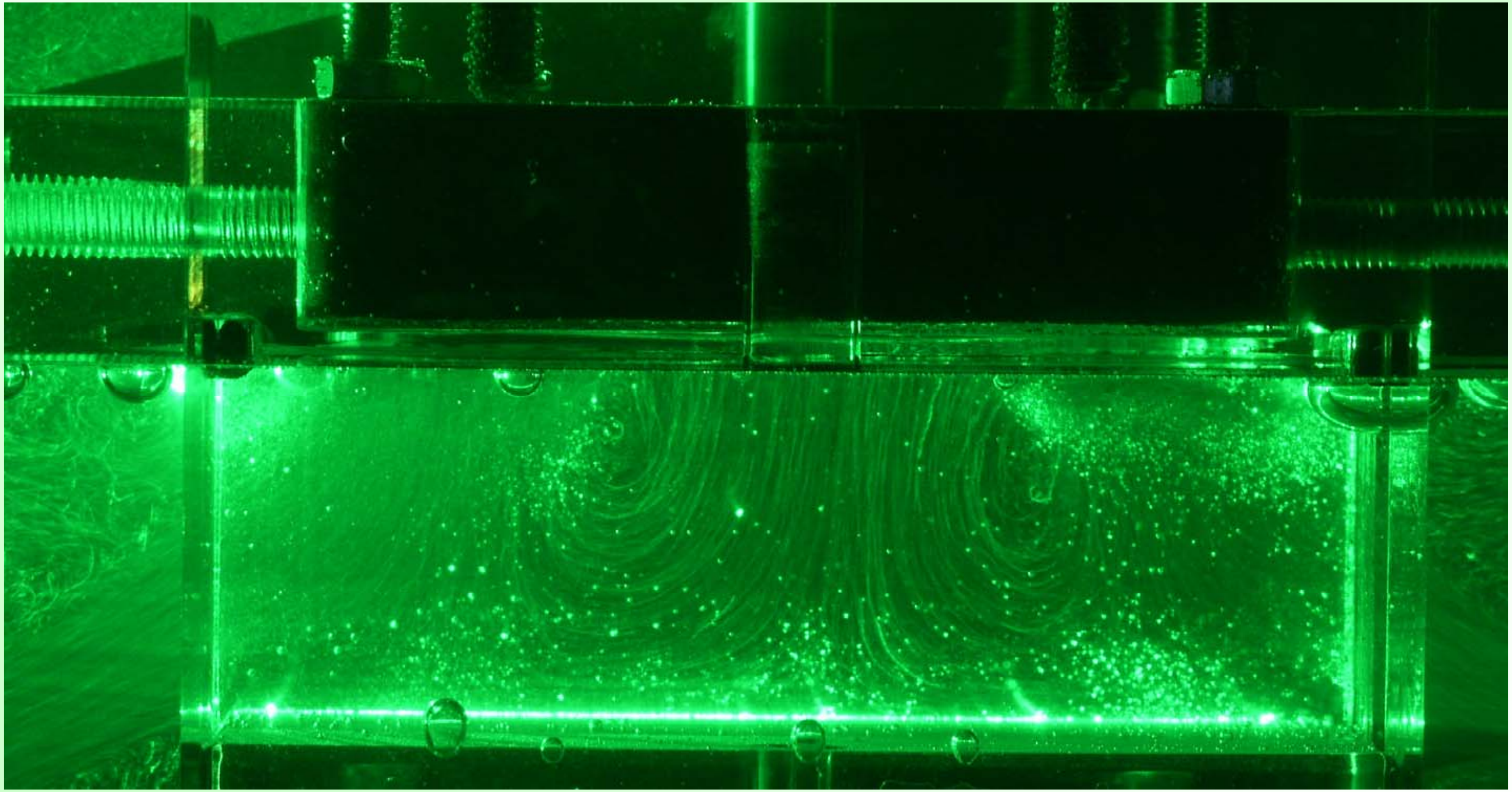


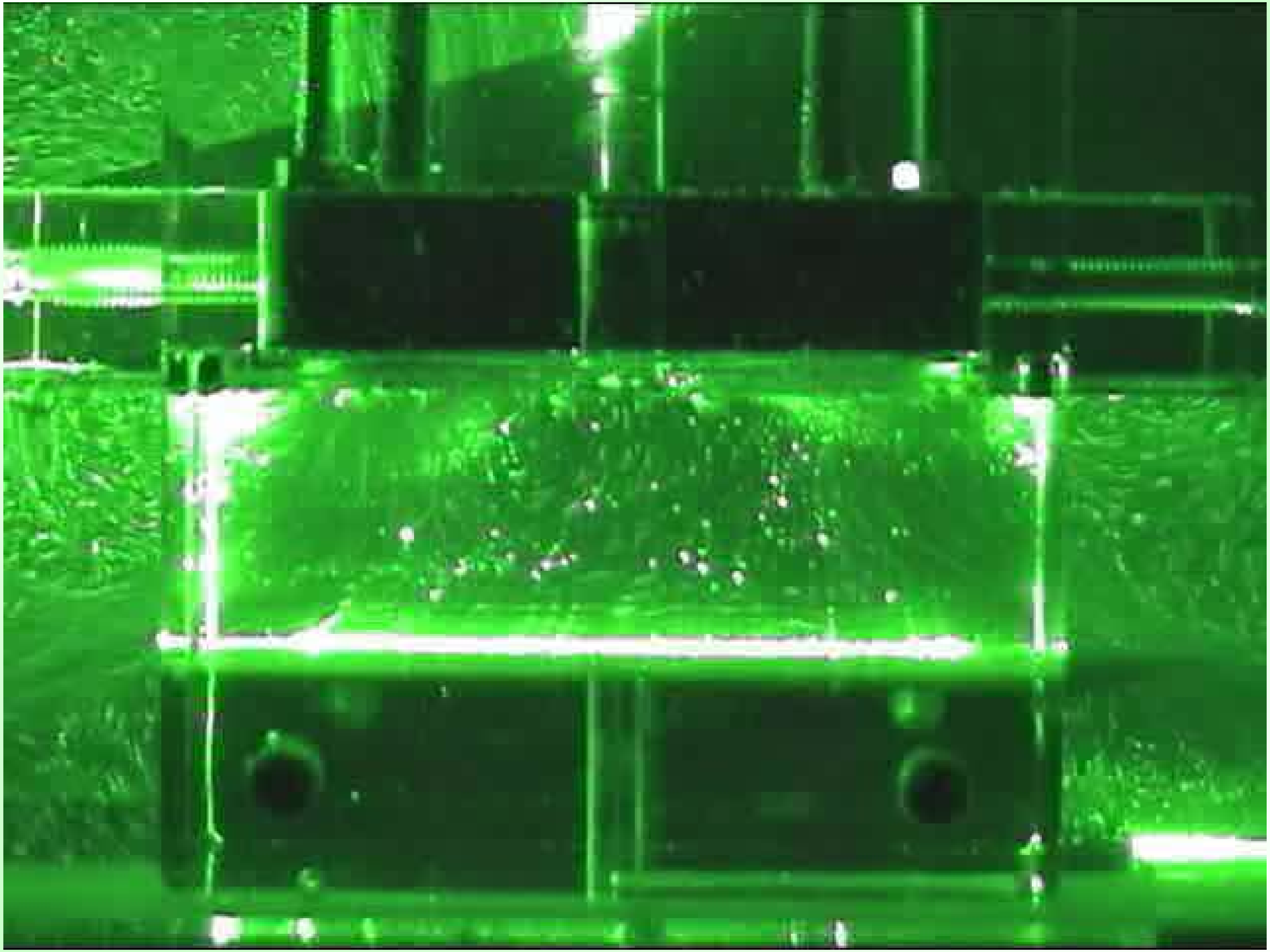


CPU cooler for D/T PC

fin：32 mm high × 76 mm width ×26 gaps

heat sink #12 gap flow field

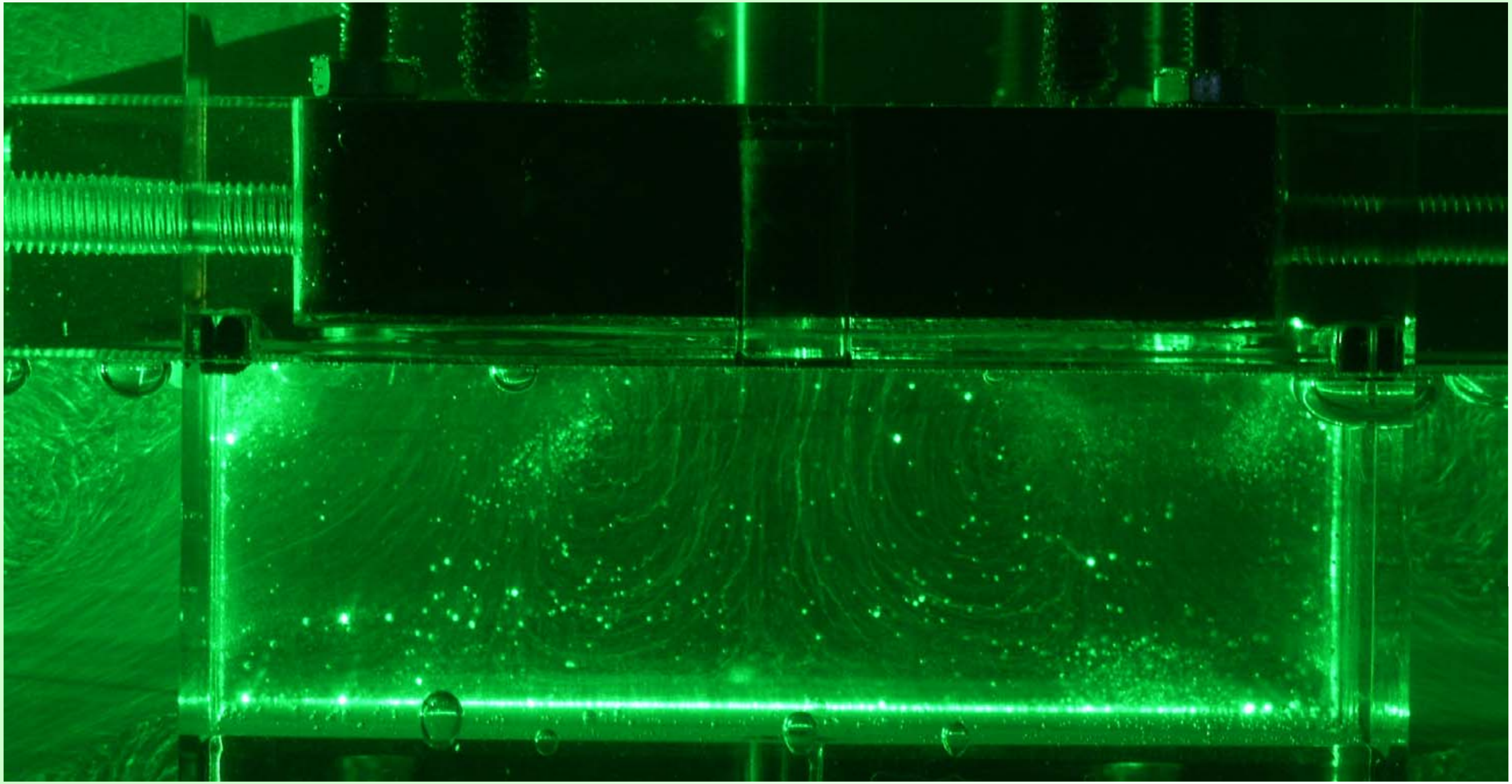


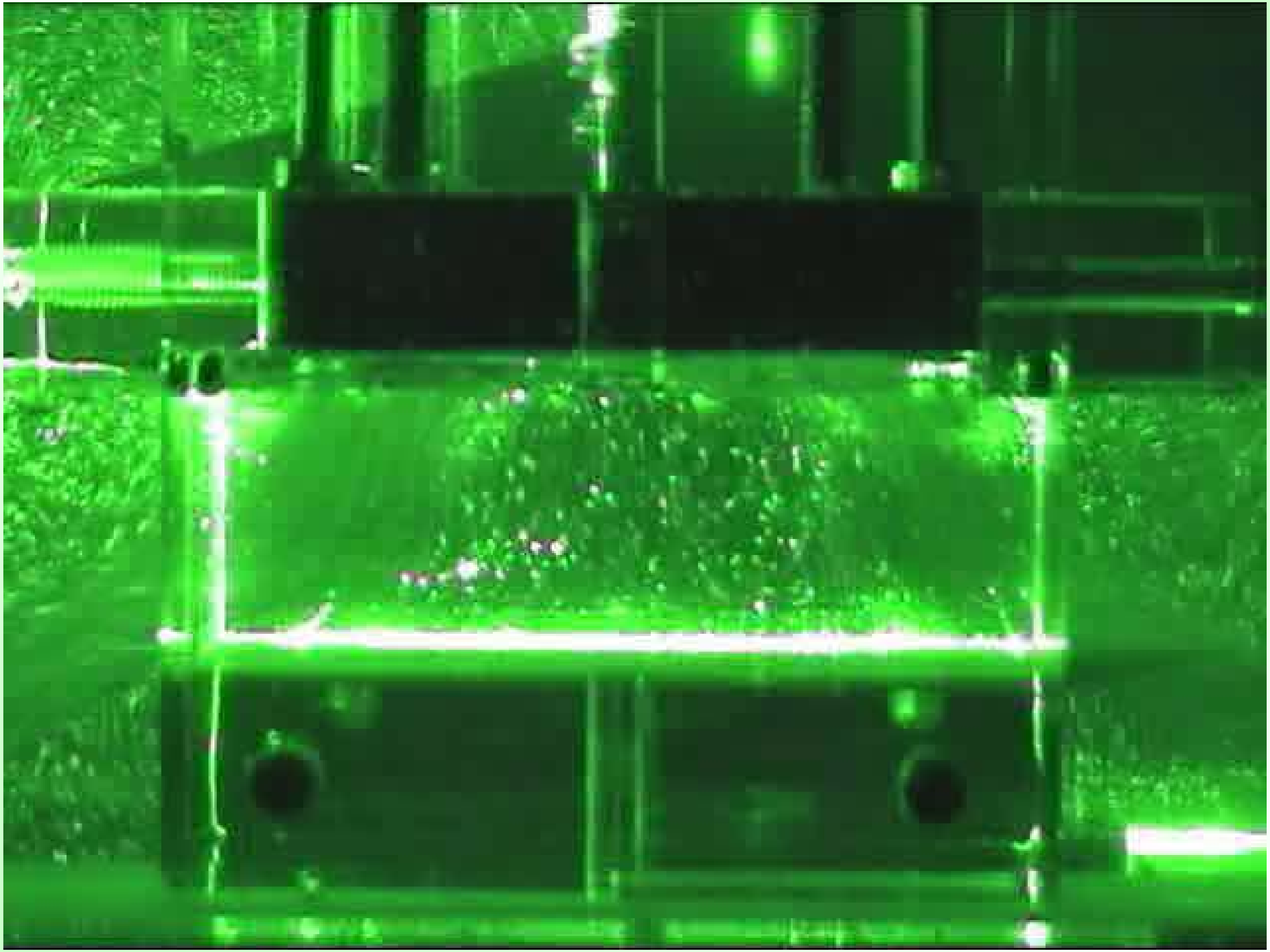


CPU cooler for D/T PC

fin：32 mm high × 76 mm width ×26 gaps

heat sink #15 gap flow field

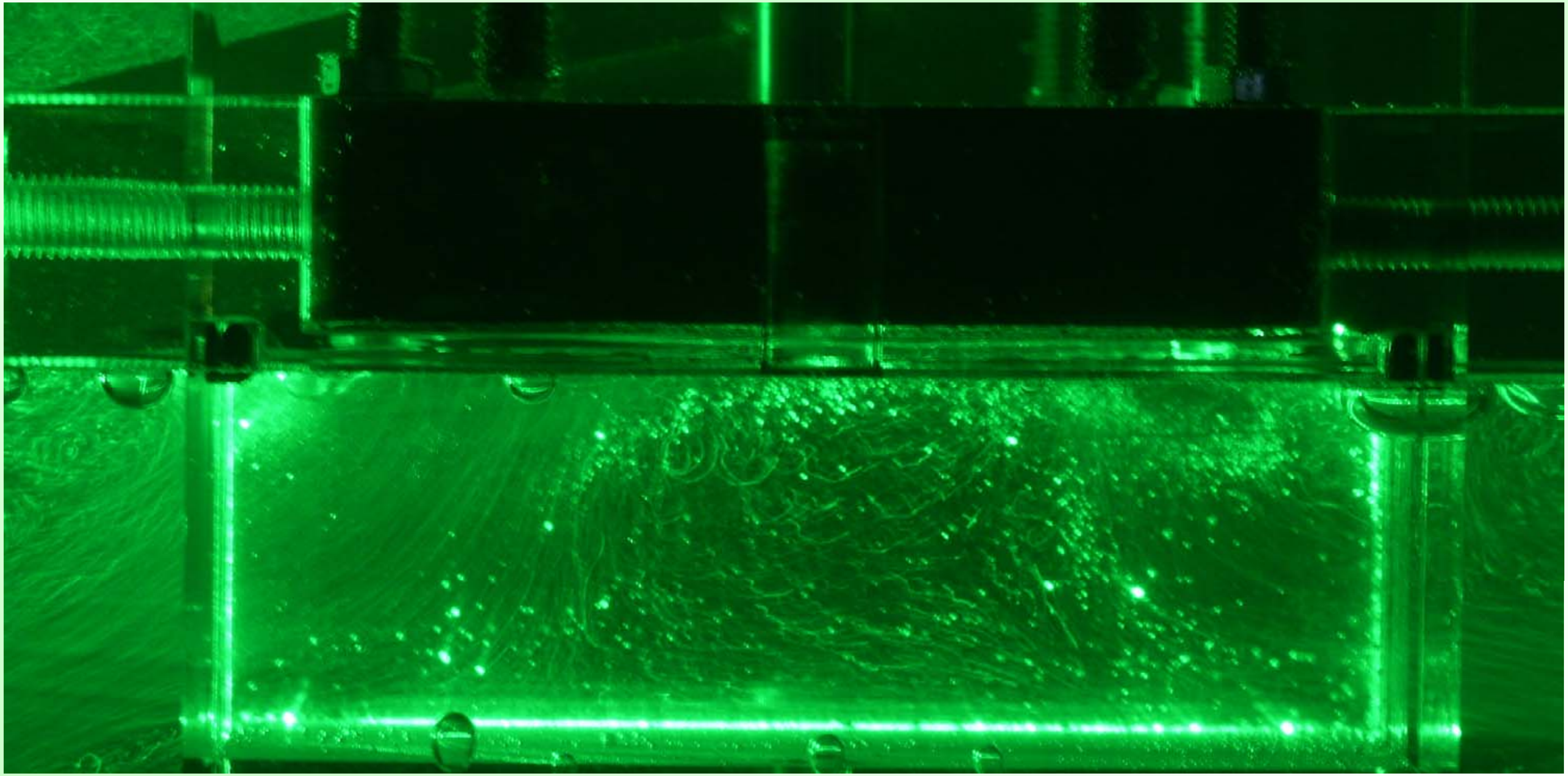


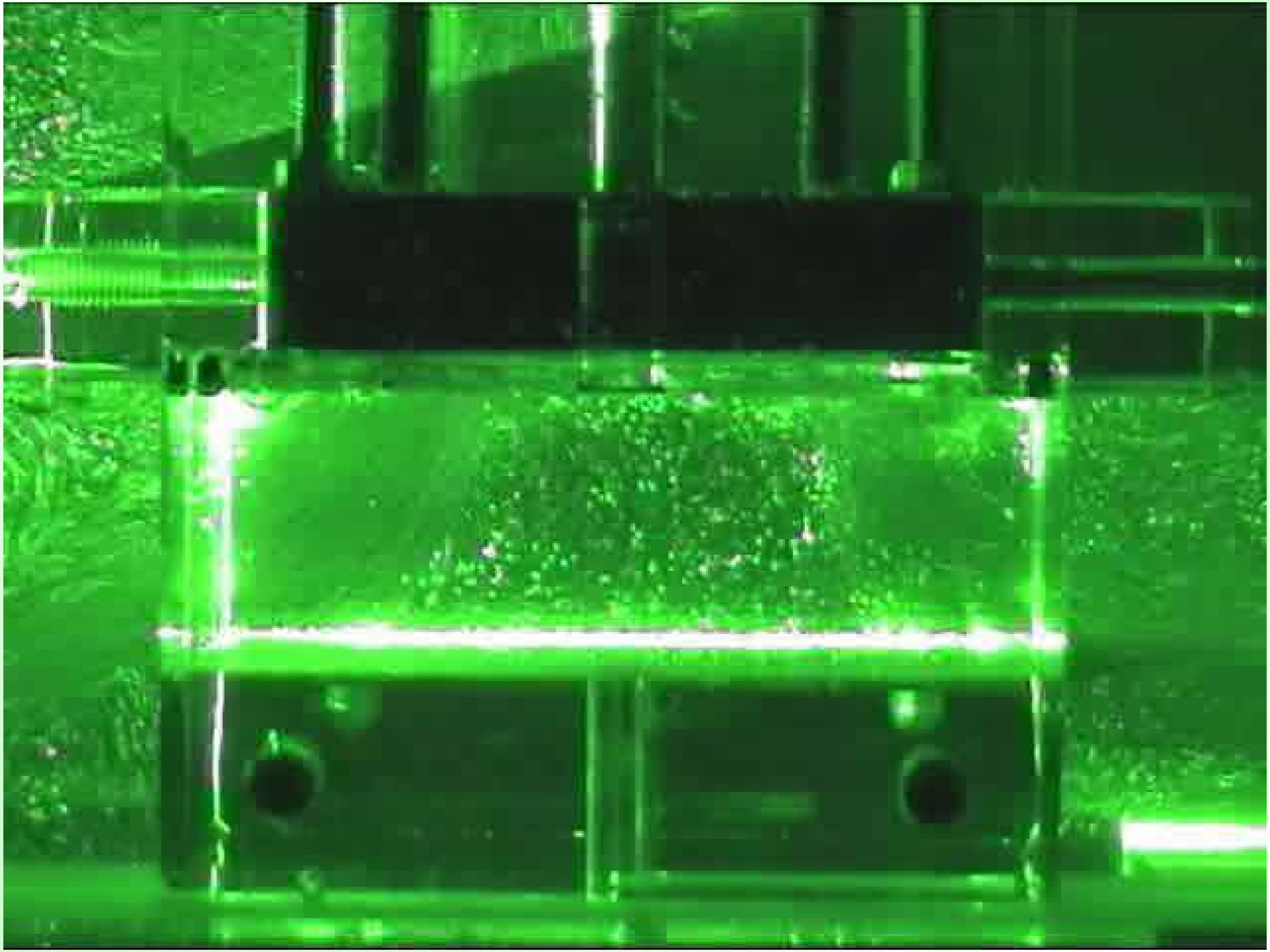


CPU cooler for D/T PC

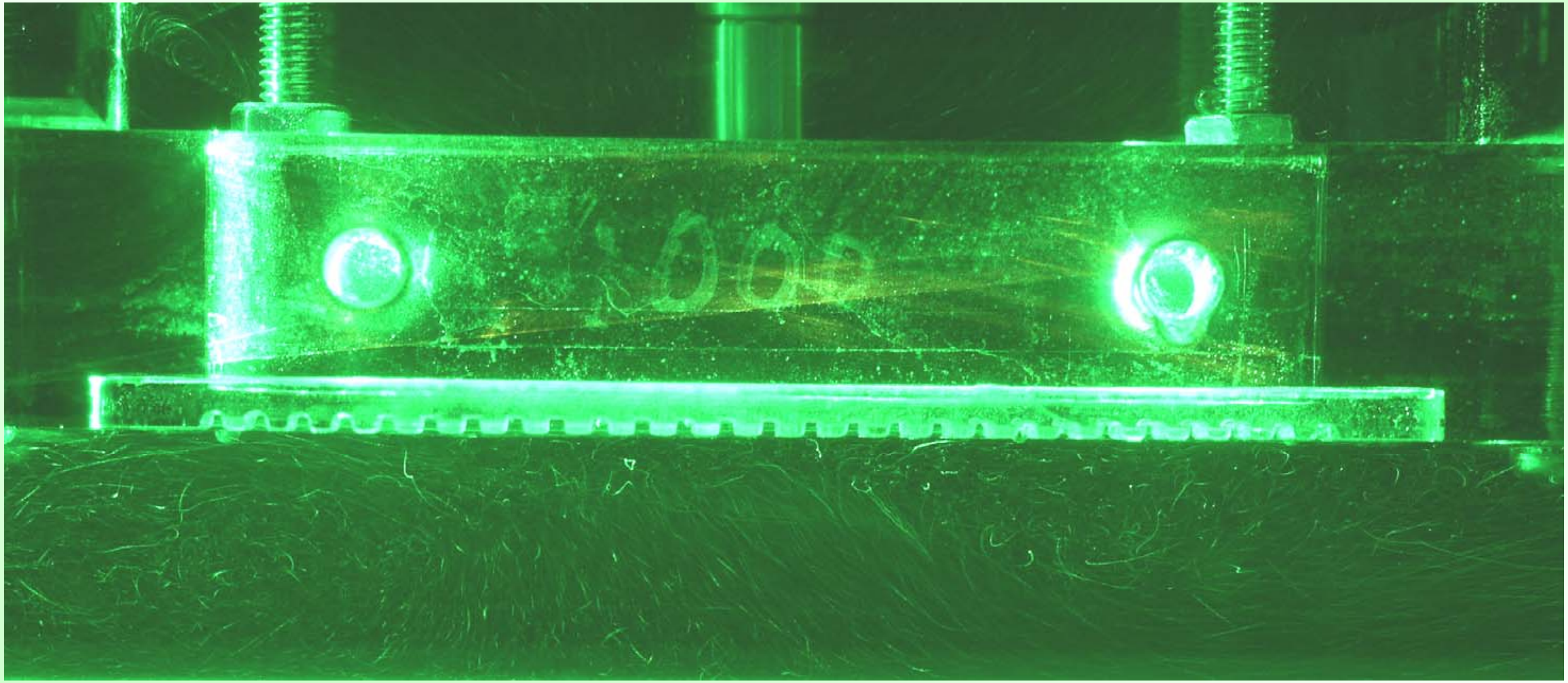
fin：32 mm high × 76 mm width ×26 gaps

heat sink #18 gap flow field



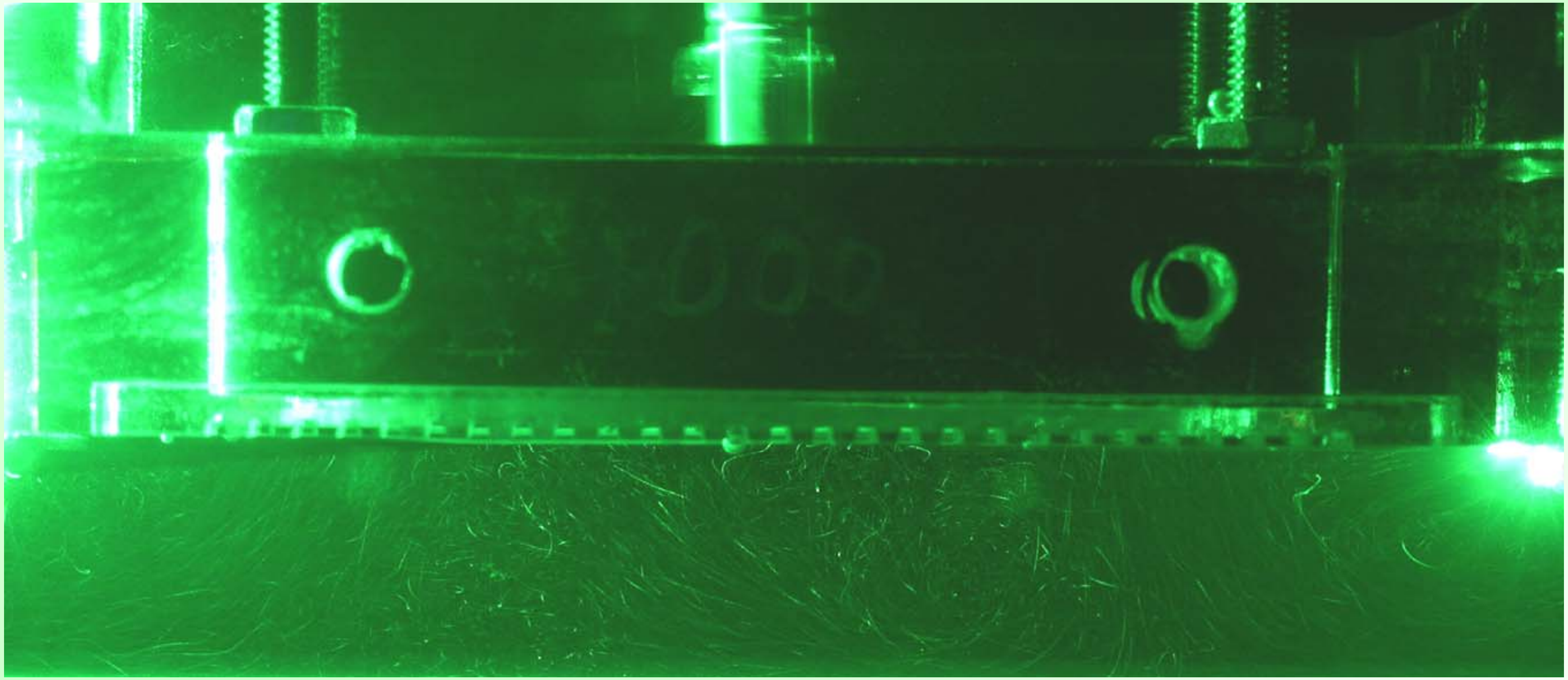


ϕ 70 fan, 20 mm space
center tangent plane flow field

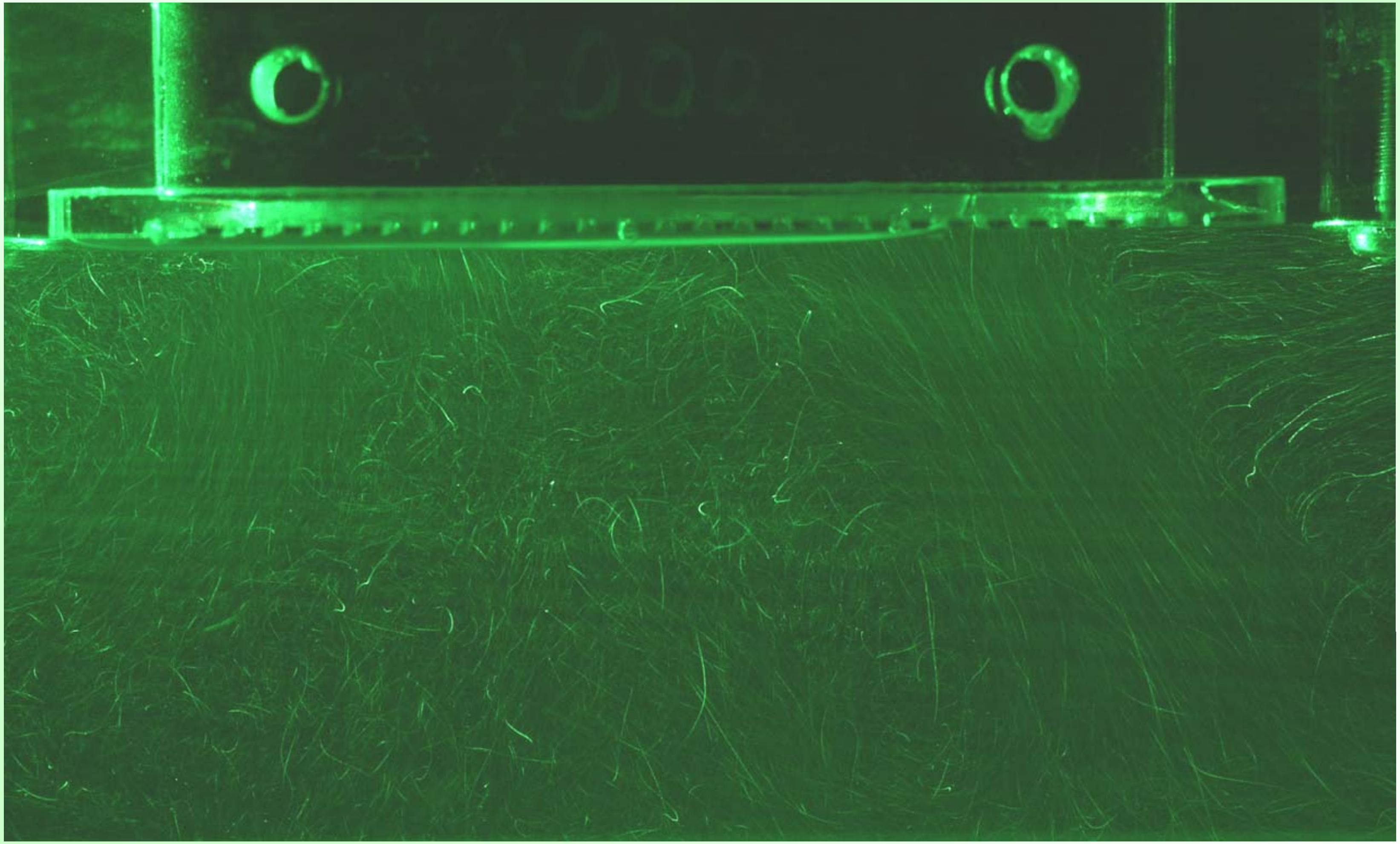


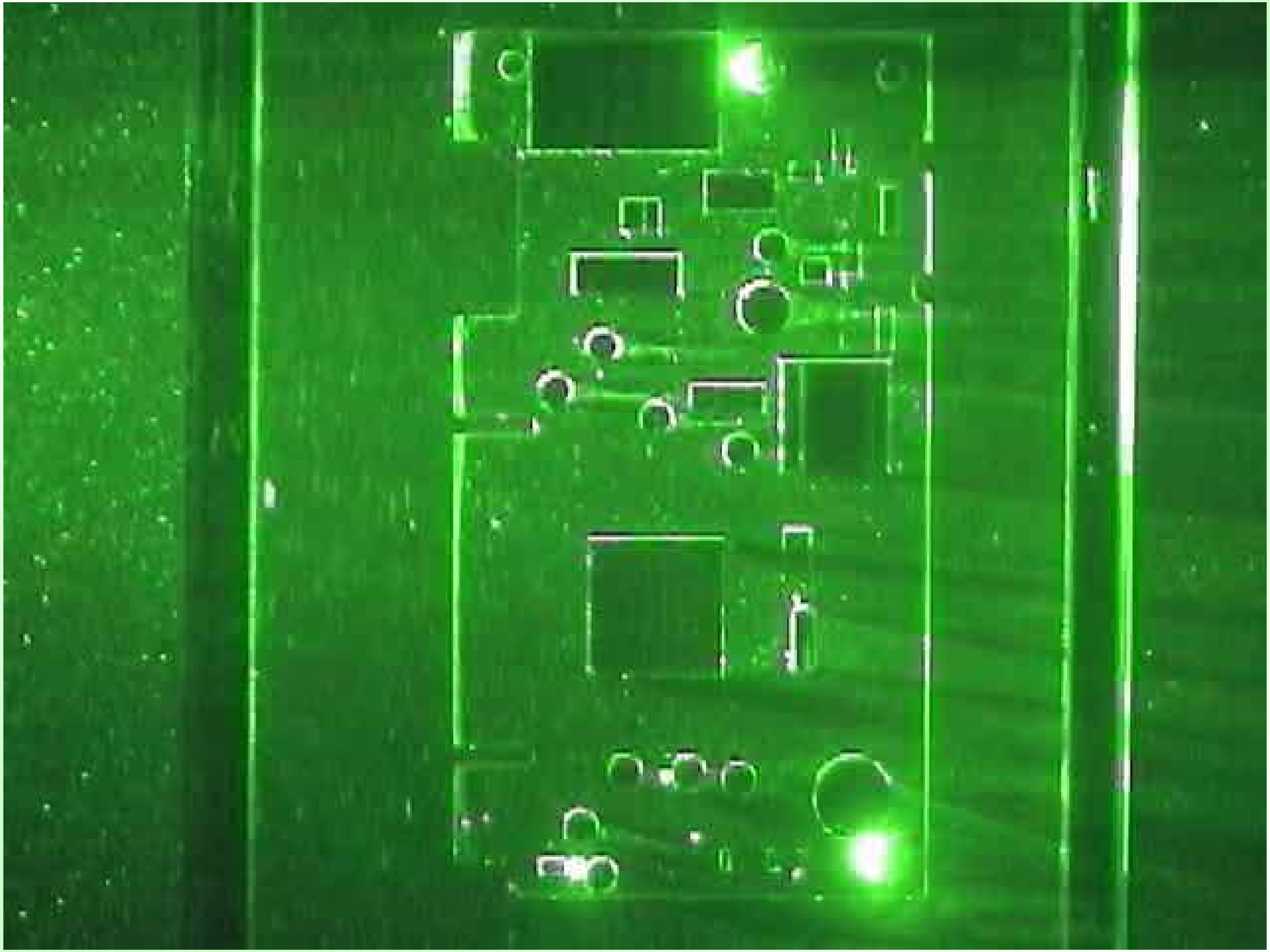
ϕ 70 fan, 20 mm space

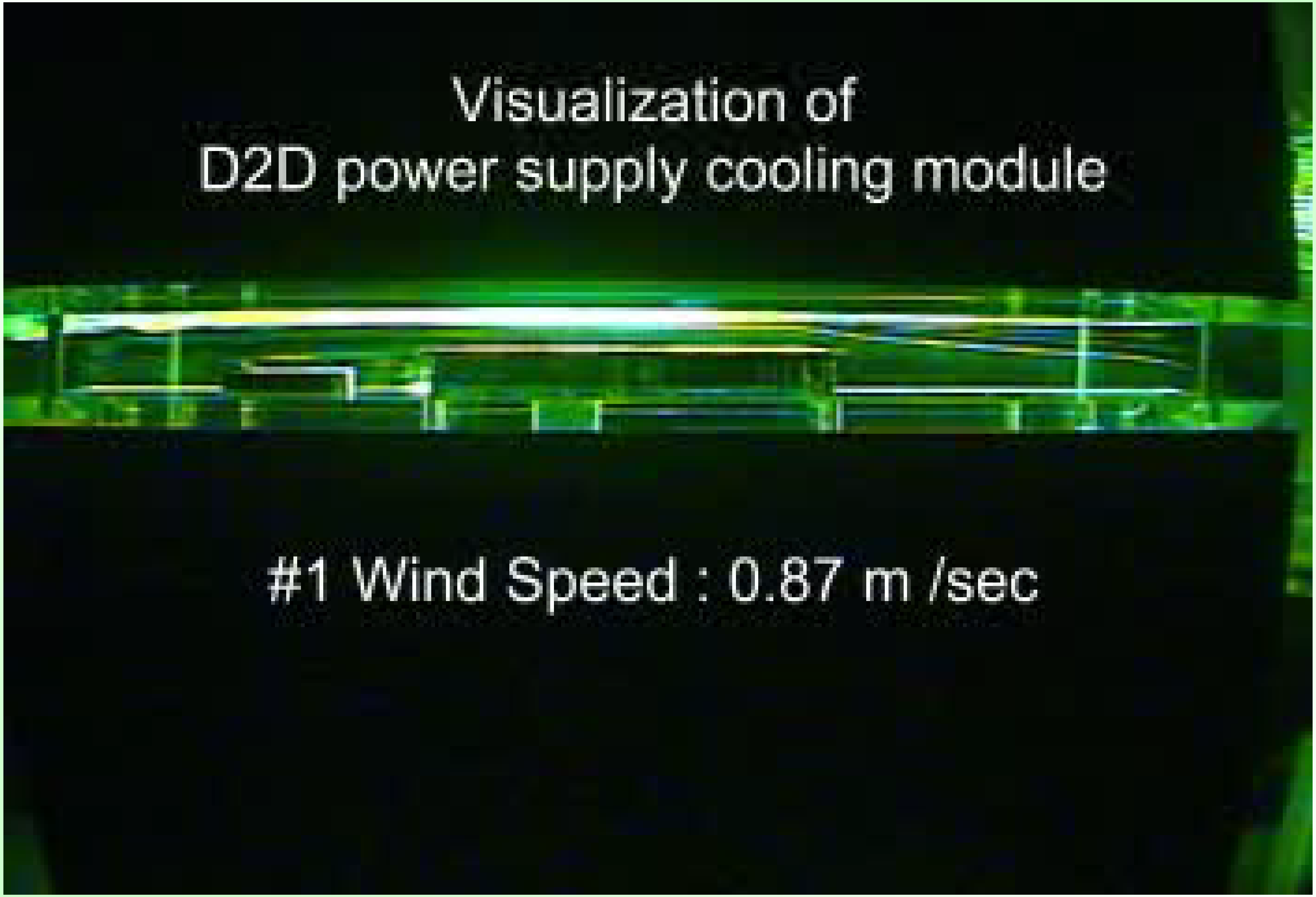
center tangent plane flow field

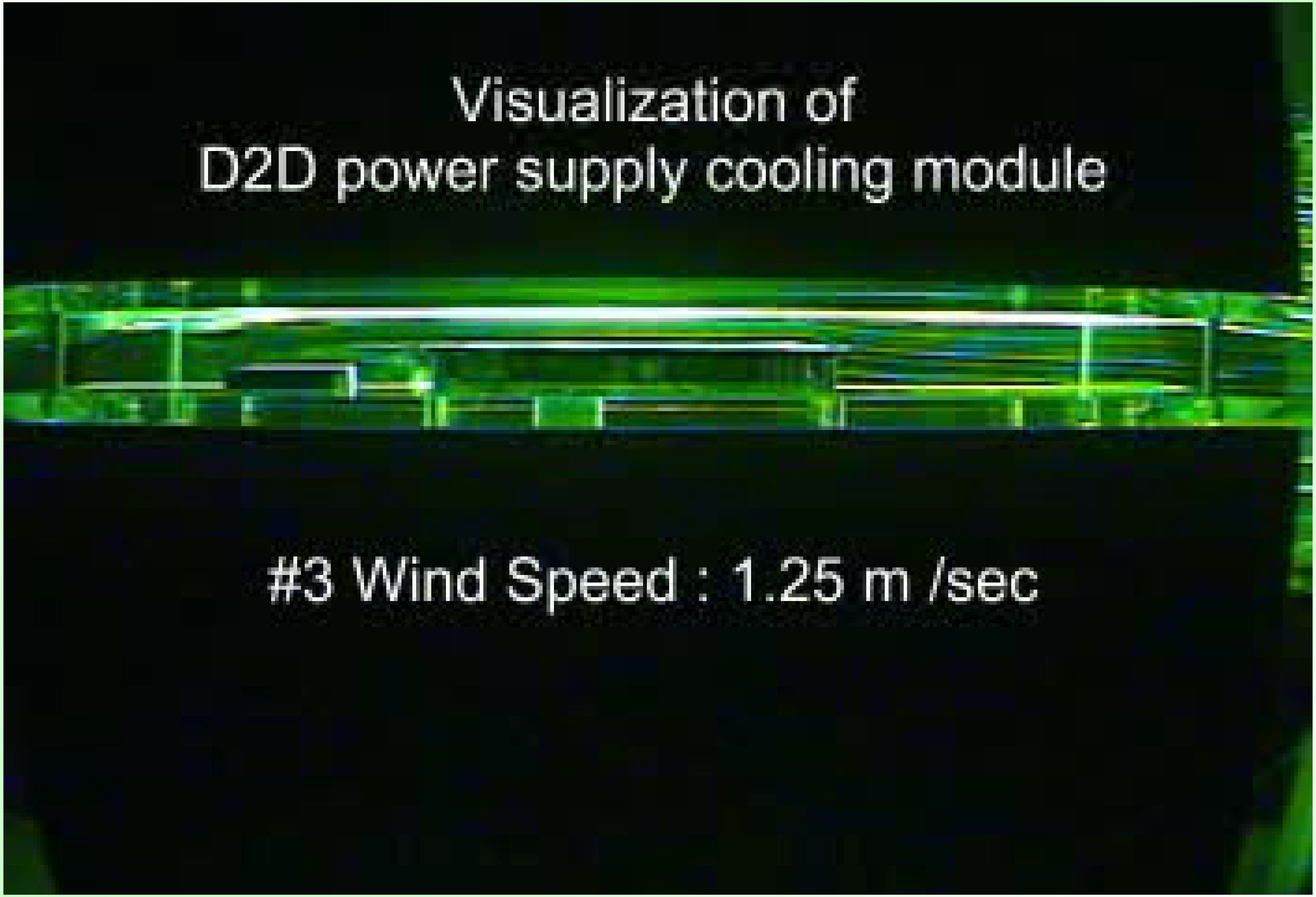


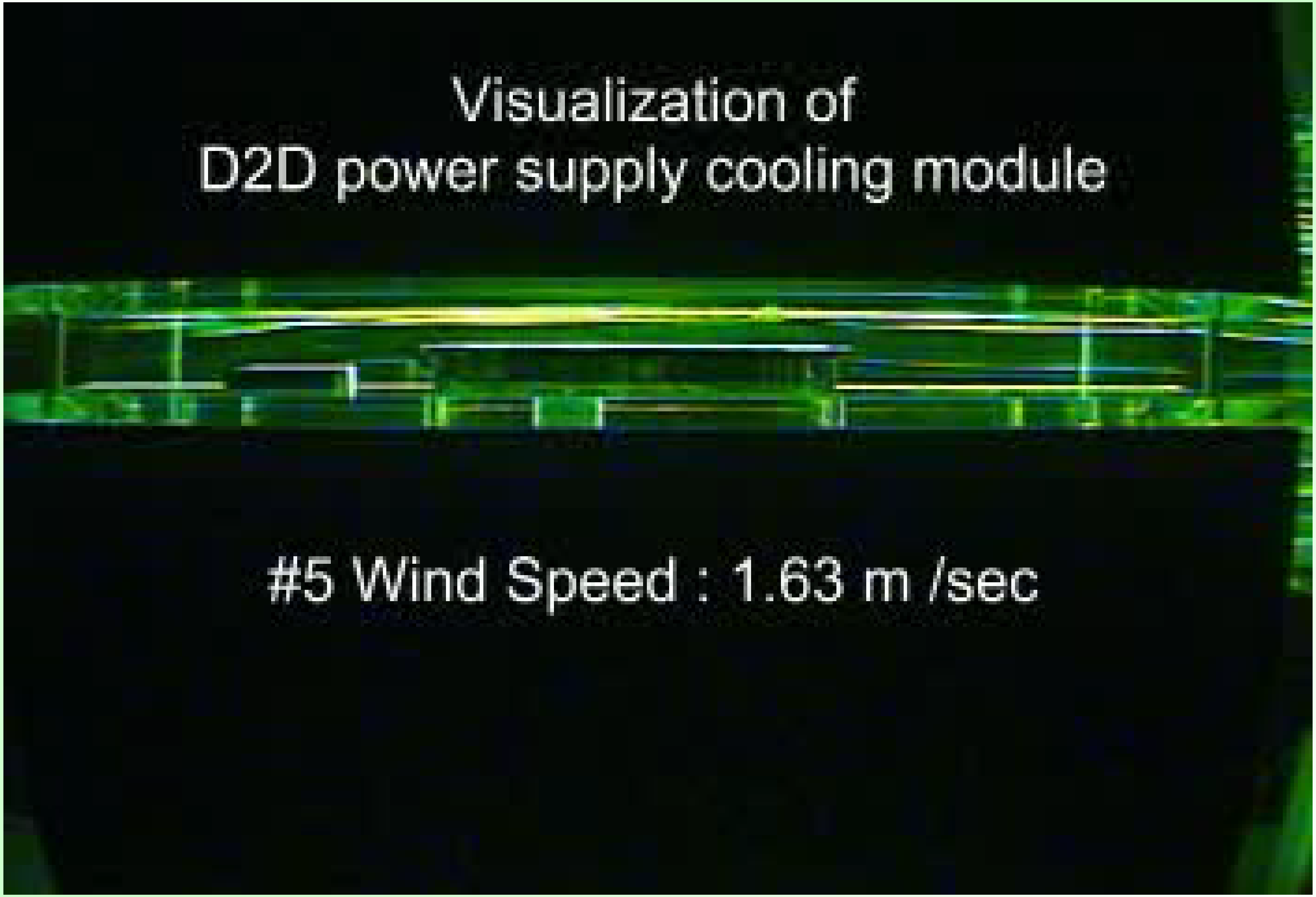
ϕ70 fan, 50 mm space
center tangent plane flow field



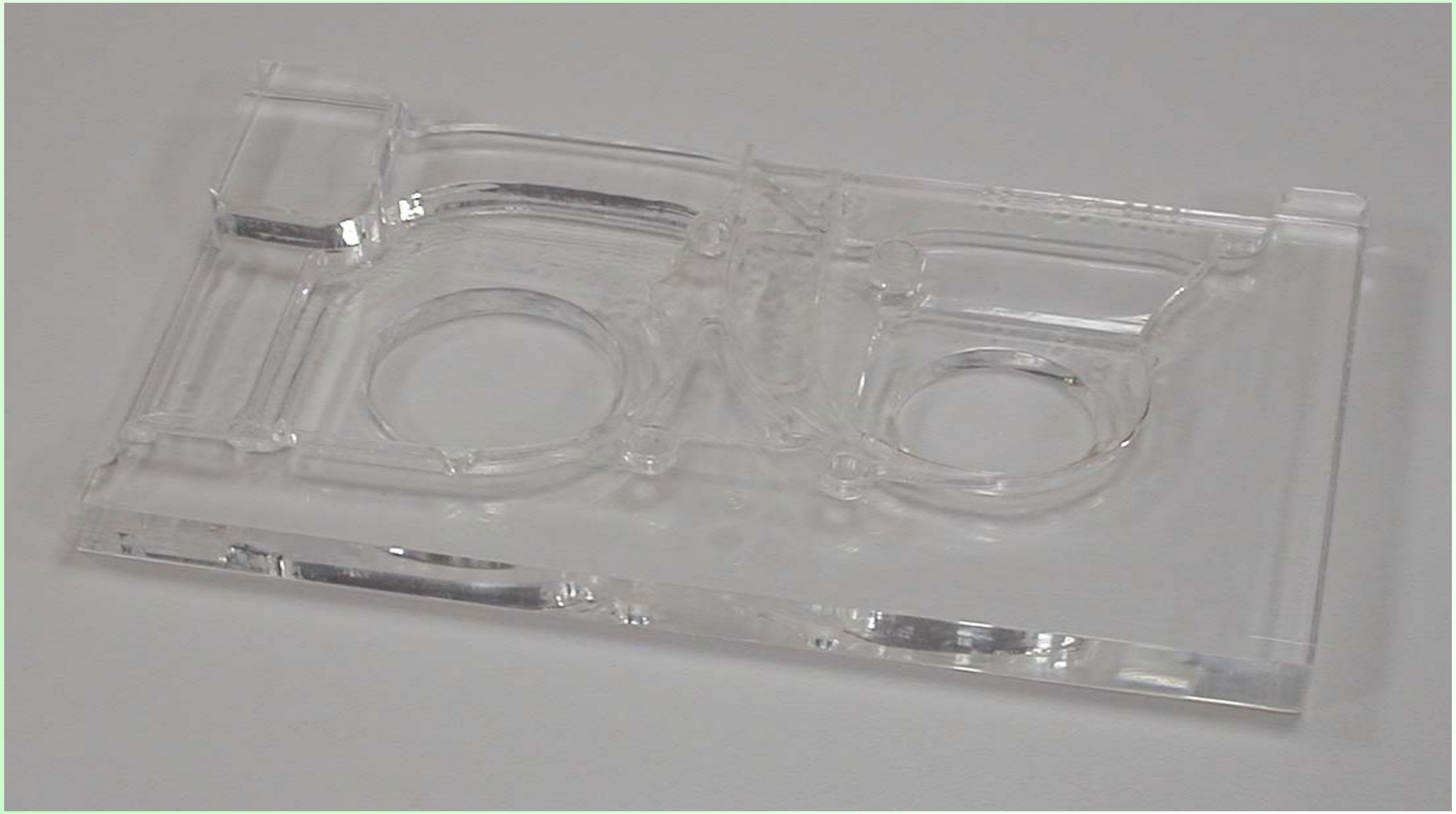



Visualization of
D2D power supply cooling module
#1 Wind Speed : 0.87 m /sec


Visualization of
D2D power supply cooling module
#3 Wind Speed : 1.25 m /sec

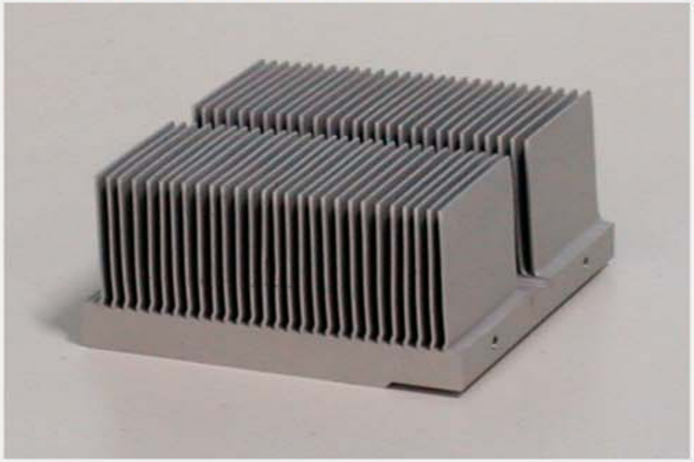

Visualization of
D2D power supply cooling module
#5 Wind Speed : 1.63 m /sec

Cooler module's Clear Model for CPU Cooler of NB, which is for Flow Visualization



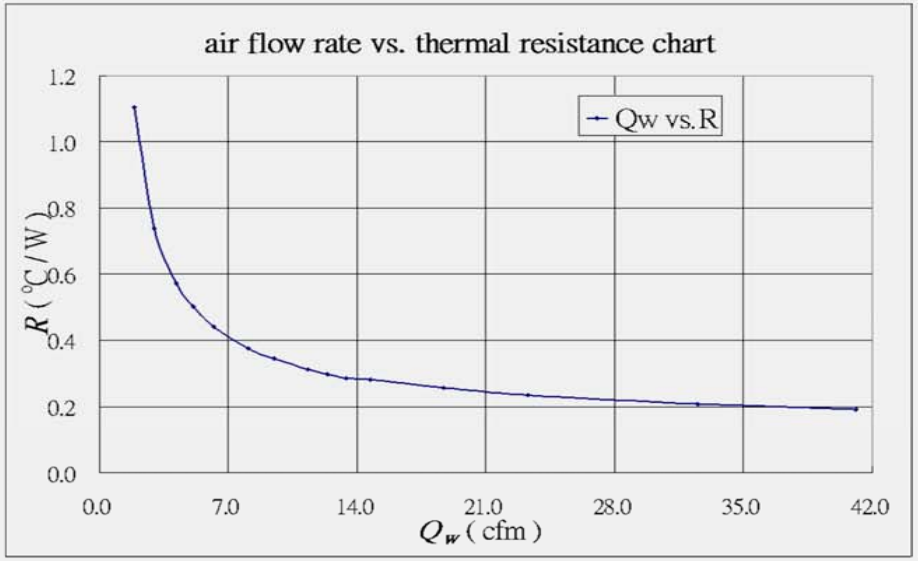
The flow pattern of the cooler module is improved. Its performance is described as below:

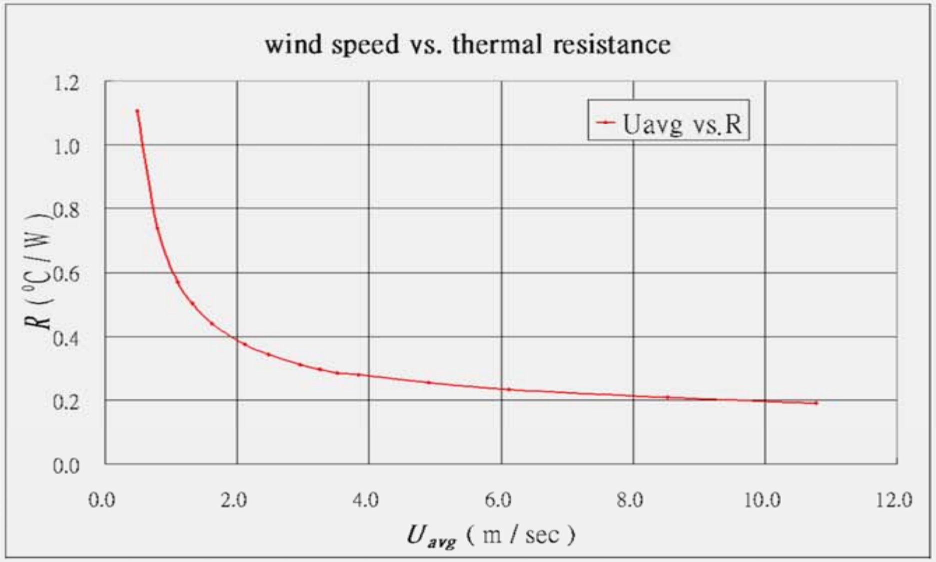
Cinderella R=0.26



Heat sink specification	
material:	A6061F
process:	skiving
base:	60 x 60 mm
fin hight:	22 mm
fin thickness:	0.5 mm
fin gap:	1.3 mm
fin number:	28 sheets
weight:	118 gram
die dimension:	31 x 31 mm
press load:	26 lb

(℃)	(℃)	(W)	(℃/W)	(cfm)	(m/sec)	LFM
20.0	98.05	70.6	1.11	1.9	0.49	96
20.0	74.00	73.1	0.74	3.0	0.80	157
20.0	61.86	73.3	0.57	4.2	1.10	216
20.0	59.60	73.5	0.50	5.1	1.33	262
20.0	52.66	74.2	0.44	6.2	1.62	319
20.0	47.98	74.5	0.38	8.1	2.12	417
20.0	45.66	74.5	0.34	9.5	2.48	488
20.0	43.43	74.7	0.31	11.3	2.96	583
20.0	42.31	74.7	0.30	12.4	3.25	640
20.0	41.41	74.7	0.29	13.4	3.52	693
20.0	40.75	73.8	0.28	14.7	3.84	756
20.0	39.28	74.7	0.26	18.7	4.90	964
20.0	37.45	74.9	0.23	23.3	6.12	1204
20.0	35.70	75.1	0.21	32.5	8.52	1677
20.0	34.42	75.1	0.19	41.1	10.78	2122





C. Radiation:

High temperature solid state surface transfers the heat to low temperature solid state surface or surroundings by means of electromagnetic wave type.

$$Q = \sigma \varepsilon F_{hc} A\left(T_h{}^4 - T_c{}^4\right)$$

Q：transferred heat

σ ：Stefan-Boltzmann's constant 5.669 x 10 $^{-8}$ $w/m^2 \bullet K^4$

ε ：Radiation rate

Fhc：shape factor

A：effective radiation area of high temperature solid state structure

Th：surface temperature of high temperature solid state structure

Tc：surface temperature of being radiated element

III. Electronic components being related to heat transfer － element, component, system －

Thermal physical meaning:

1. Elements:

A. Cooling fan: PQ description, and effect of chamber and altitude

B. Heat sink: description of heat dissipation capability, T-Q, R-Q, T-U, R-U.

C. Thermal grease: thermal conduction or thermal resistance description

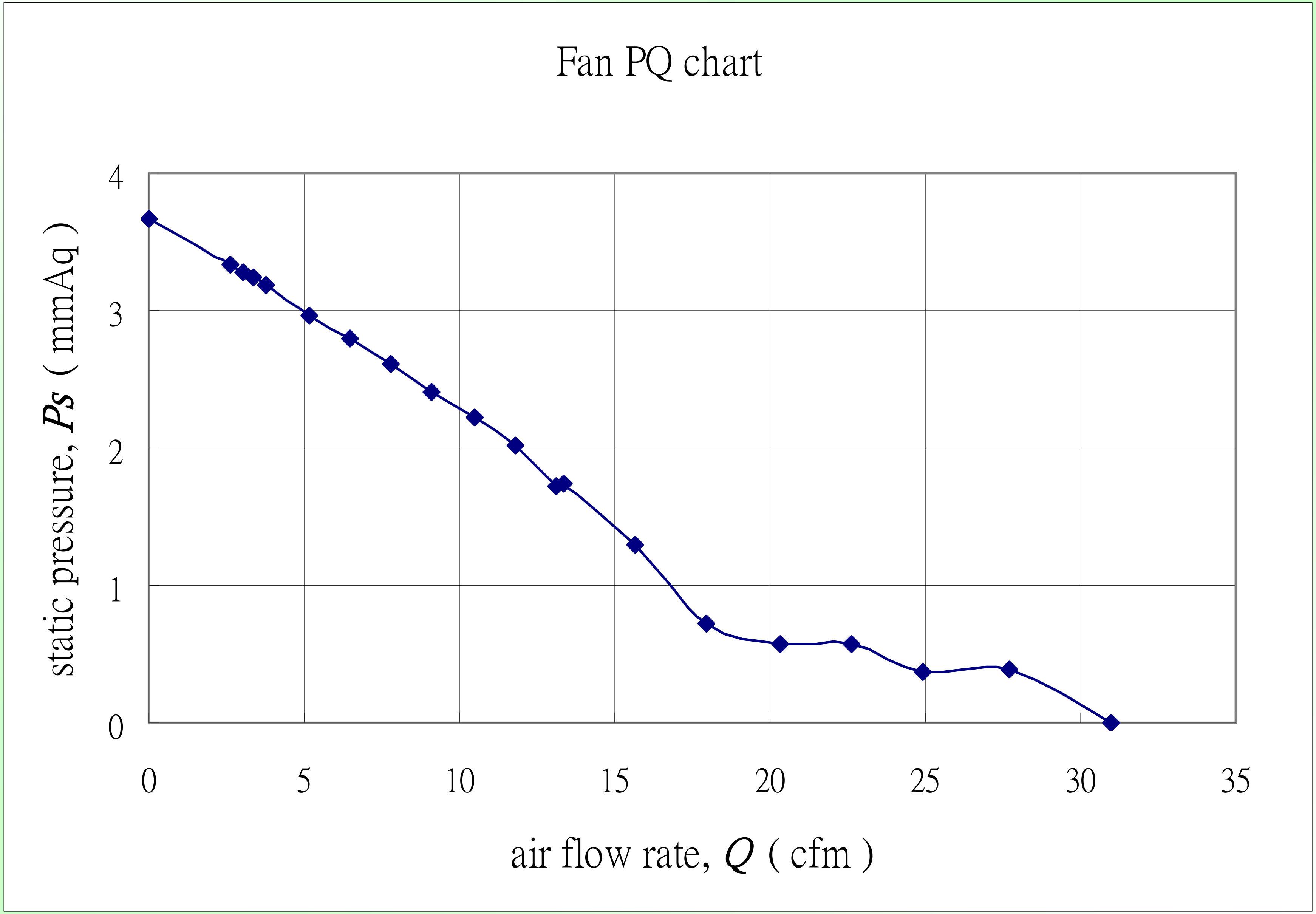
D. Thermal pad: thermal conduction or thermal resistance description

E. Heat pipe: thermal conduction description

F. Design of vent holes on PC case: flow resistance description

G. Thermal property of electronic elements and components, such as IC package, condenser, transformer, battery, etc.

- a. heating power
- b. temperature distribution
- c. Q-T, U-T characteristics of single element on constant heating power
- d. surface radiation rate



Fan PQ chart
static pressure, Ps (mmAq)
air flow rate, Q (cfm)
0
1
2
3
4
0
5
10
15
20
25
30
35

2. Components:

A. Power supply

B. Interface card

3. System:

A. D/T PC

B. N/B PC

C. Servo System

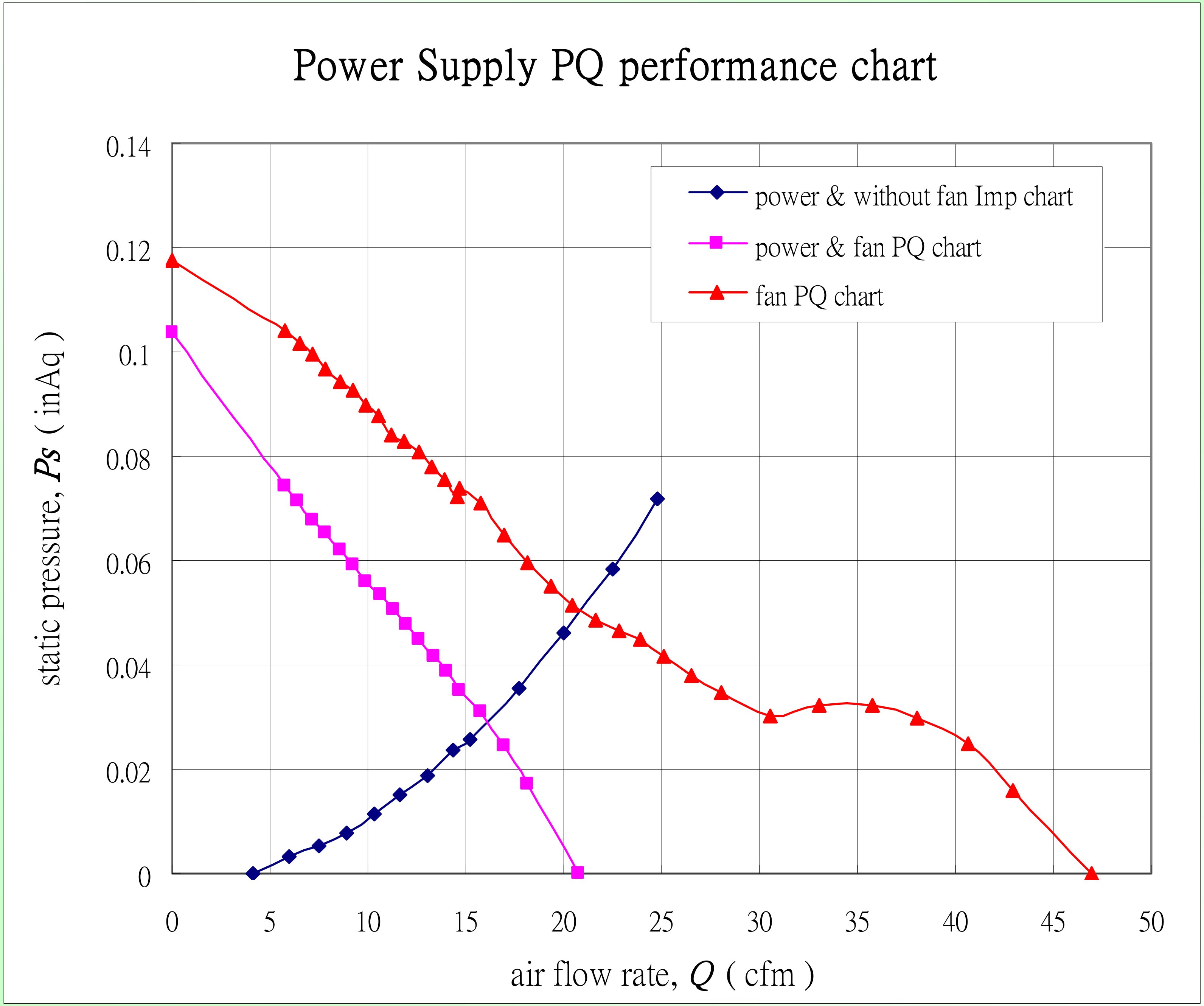
D. Rack System

E. Projector

Working Flow Rate:

Qop is the flow rate flowing into or flowing out the component or system.

The working flow rate is not absolutely equivalent to the effective flow rate.


Power Supply PQ performance chart
power & without fan Imp chart
power & fan PQ chart
fan PQ chart
static pressure, Ps (inAq)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 5 10 15 20 25 30 35 40 45 50
air flow rate, Q (cfm)

Qop ≒ 21 cfm

5. System Flow Resistance:

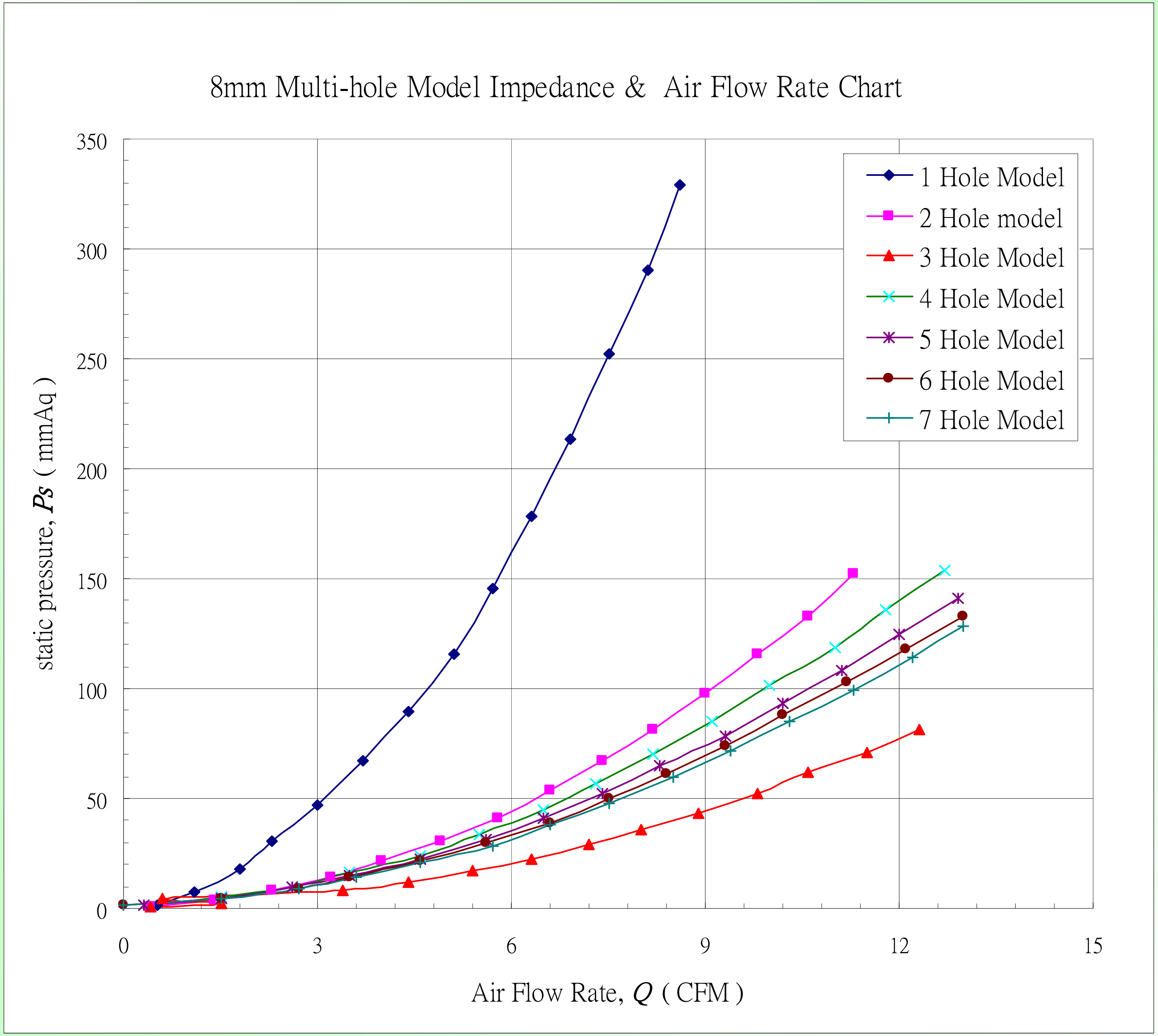
Under the same fan condition, the system flow resistance is related to the working flow rate of fan.

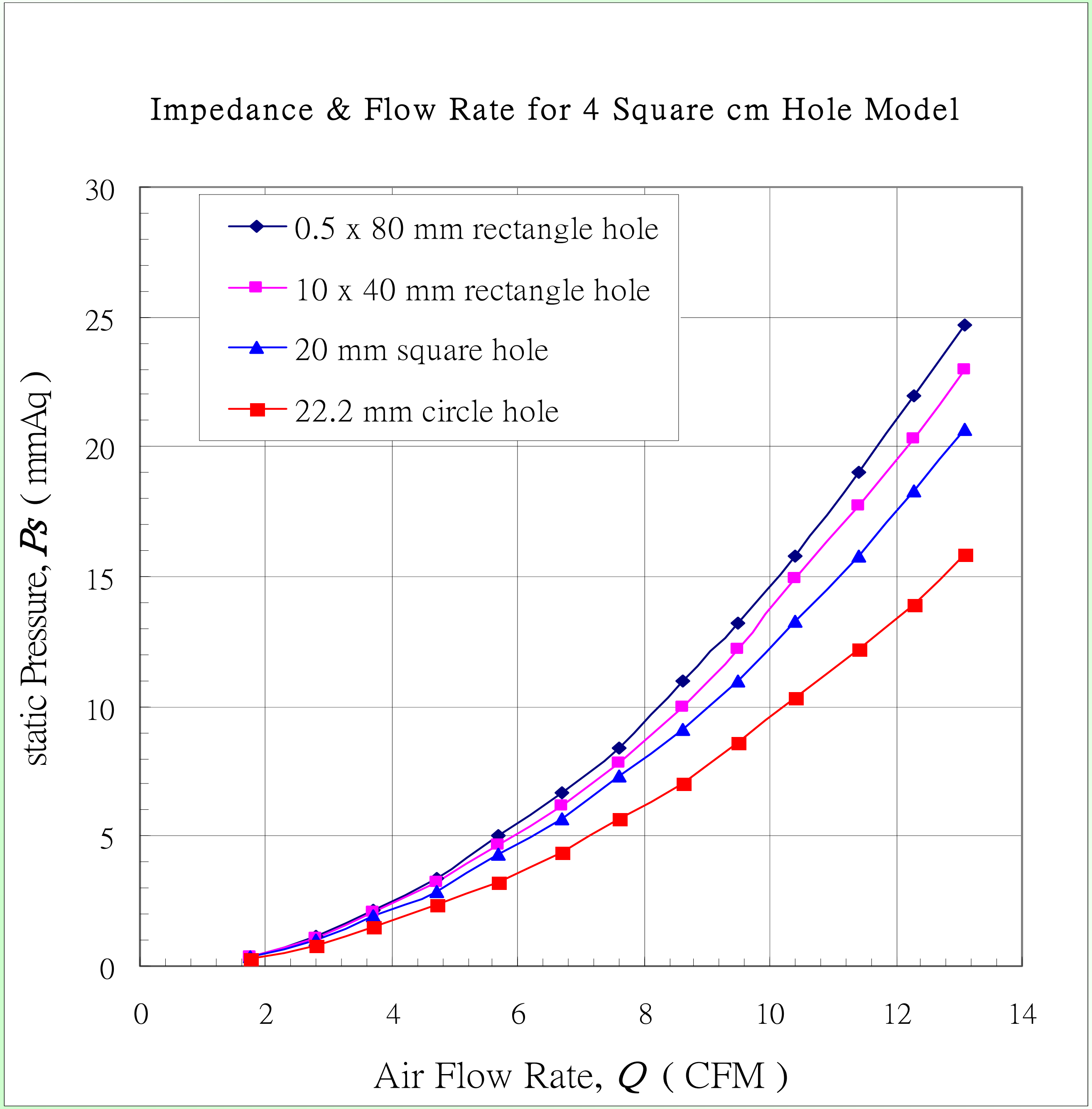
The influential factors on system flow resistance are:

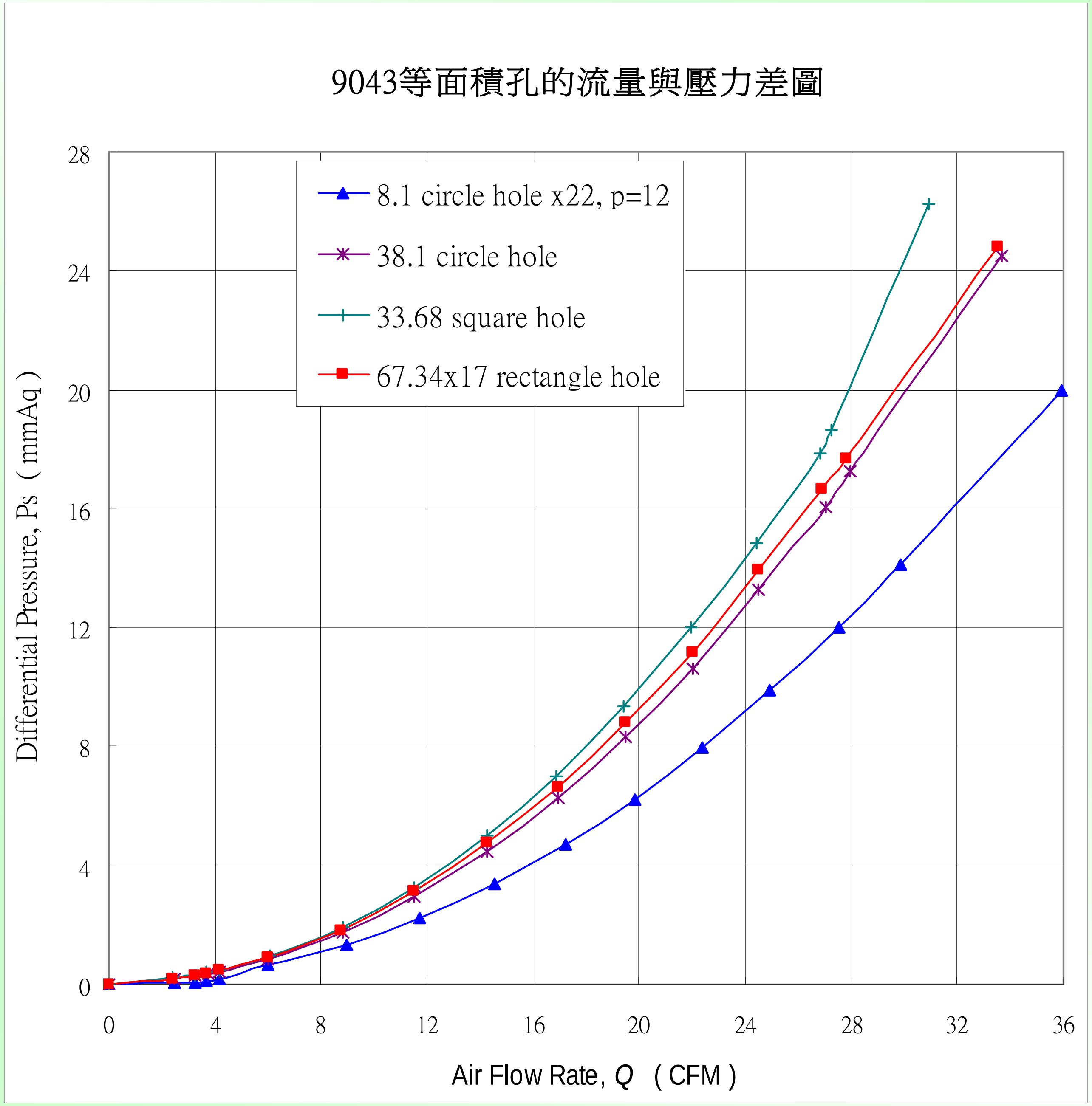
A. Effective area of vent holes

B. shape of vent holes

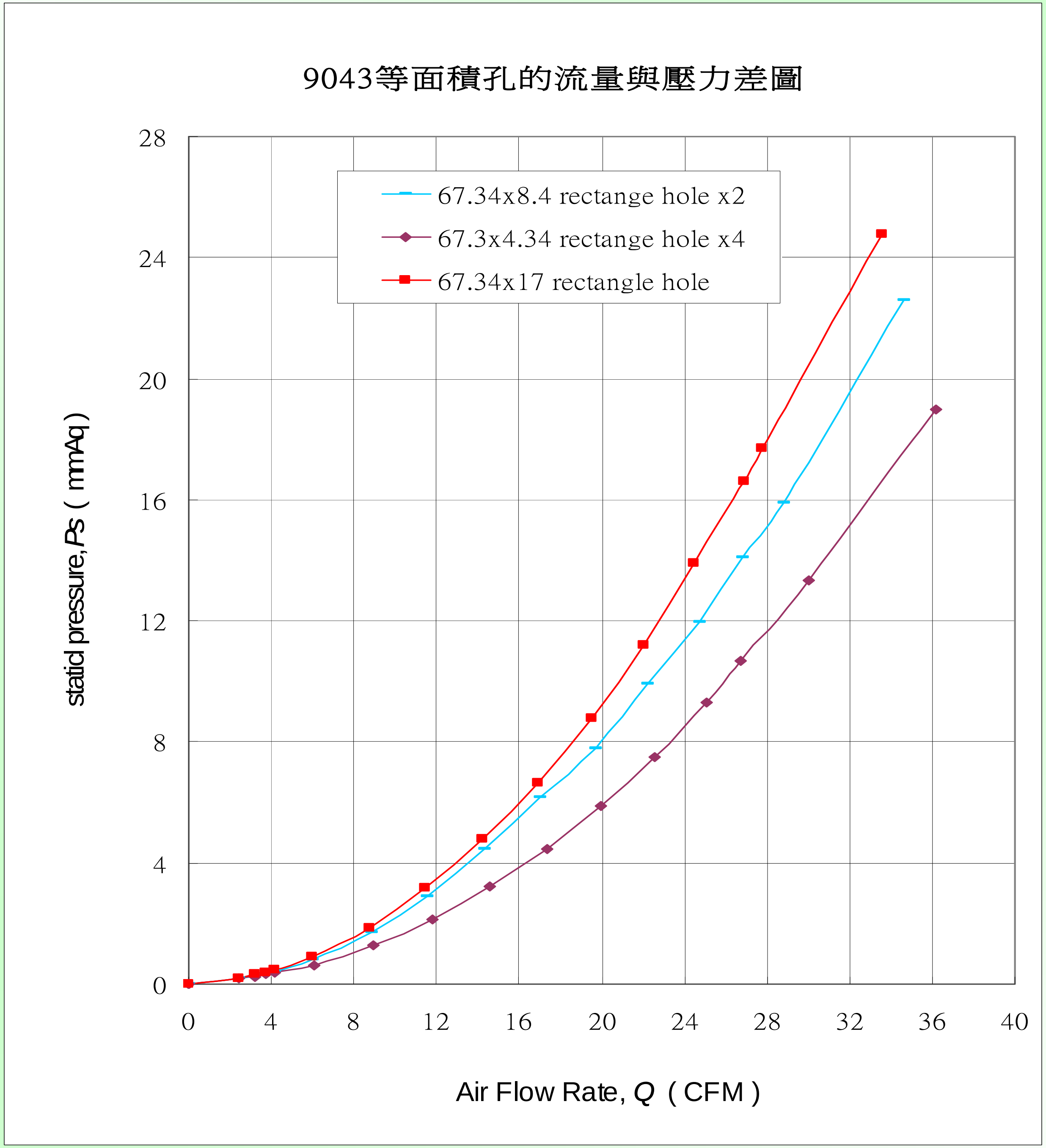
C. arrangement of vent holes


8mm Multi-hole Model Impedance & Air Flow Rate Chart
static pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
0
50
100
150
200
250
300
350
0
3
6
9
12
15
1 Hole Model
2 Hole model
3 Hole Model
4 Hole Model
5 Hole Model
6 Hole Model
7 Hole Model

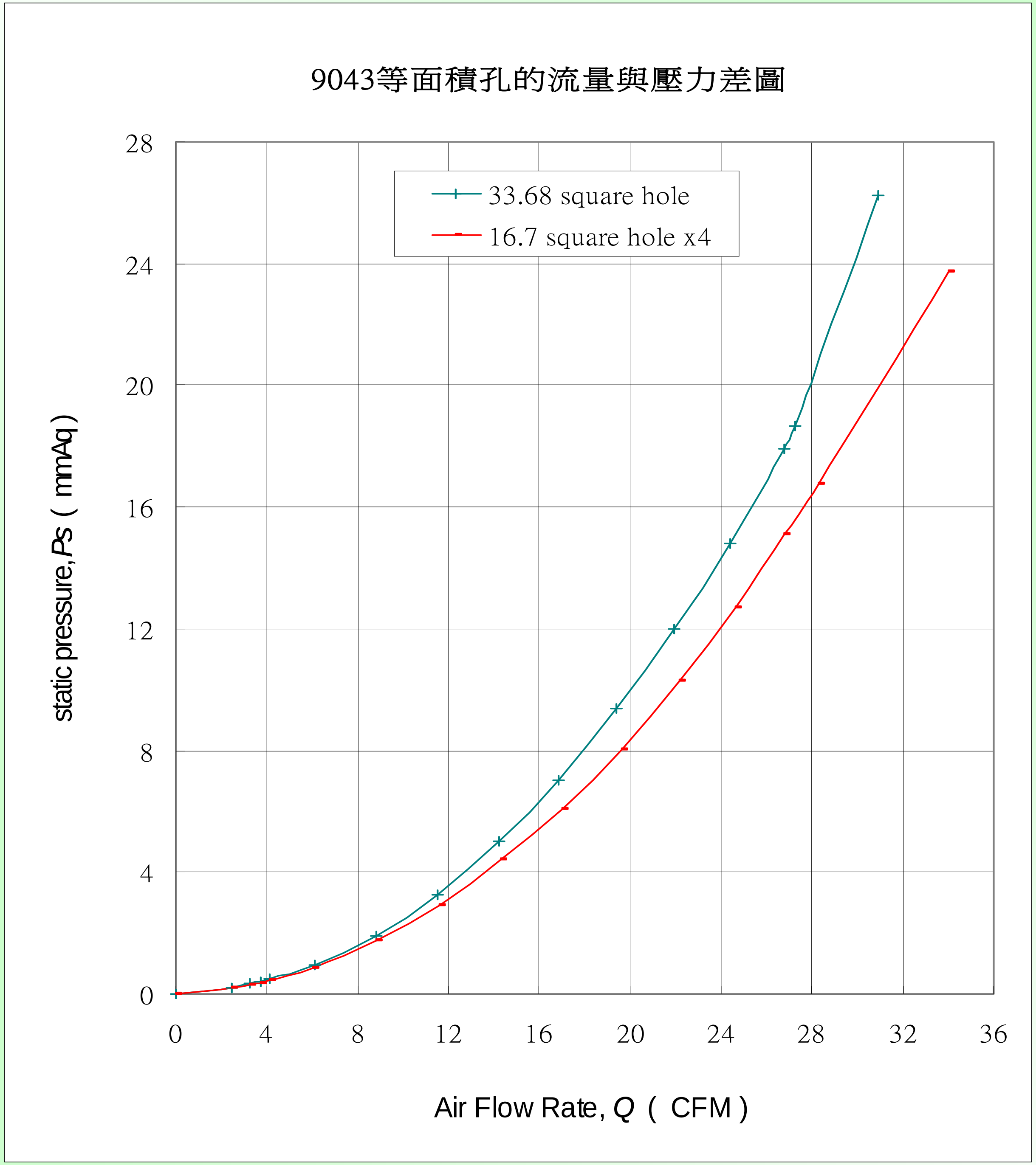

Impedance & Flow Rate for 4 Square cm Hole Model
0.5 x 80 mm rectangle hole
10 x 40 mm rectangle hole
20 mm square hole
22.2 mm circle hole
static Pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
0
5
10
15
20
25
30
0
2
4
6
8
10
12
14

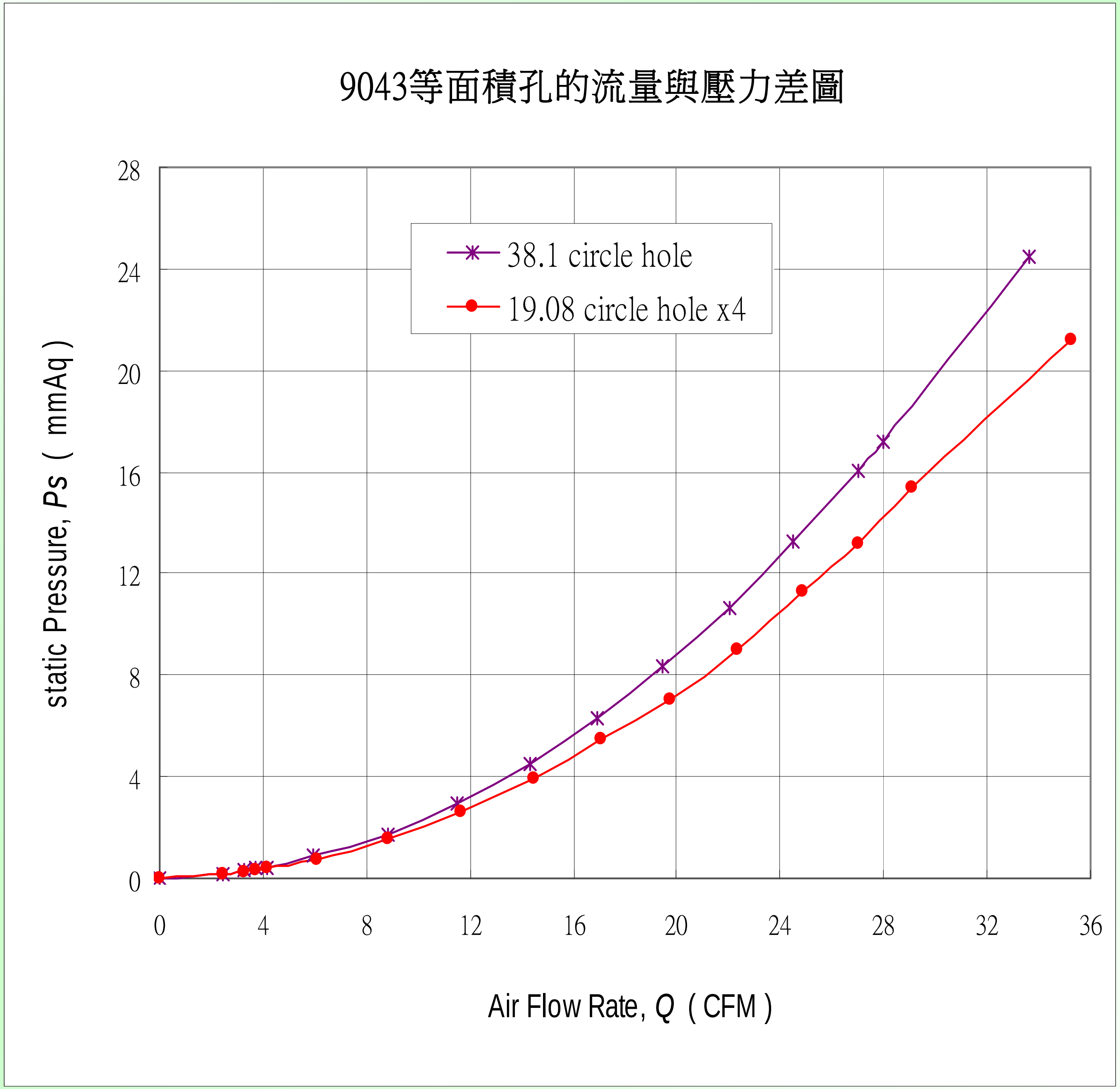


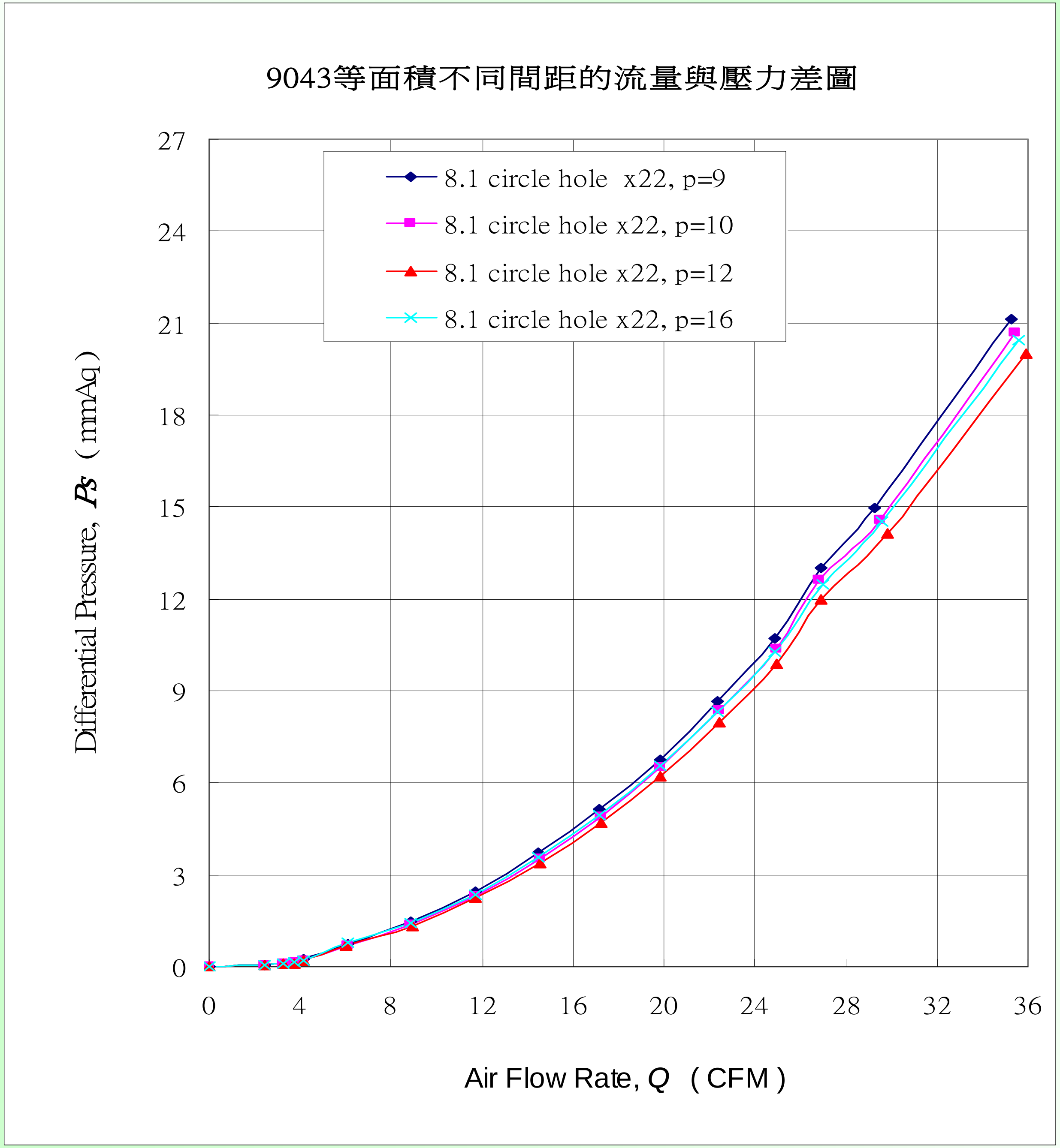
9043等面積孔的流量與壓力差圖
8.1 circle hole x22, p=12
38.1 circle hole
33.68 square hole
67.34x17 rectangle hole
Differential Pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
0
4
8
12
16
20
24
28
32
36



9043等面積孔的流量與壓力差圖
static pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
67.34x8.4 rectange hole x2
67.3x4.34 rectange hole x4
67.34x17 rectangle hole
0
4
8
12
16
20
24
28
0
4
8
12
16
20
24
28
32
36
40


9043等面積孔的流量與壓力差圖
33.68 square hole
16.7 square hole x4
static pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
0
4
8
12
16
20
24
28
32
36


9043等面積孔的流量與壓力差圖
38.1 circle hole
19.08 circle hole x4
static Pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
0
4
8
12
16
20
24
28
32
36


9043等面積不同間距的流量與壓力差圖
8.1 circle hole x22, p=9
8.1 circle hole x22, p=10
8.1 circle hole x22, p=12
8.1 circle hole x22, p=16
Differential Pressure, Ps (mmAq)
Air Flow Rate, Q (CFM)
0
3
6
9
12
15
18
21
24
27
0
4
8
12
16
20
24
28
32
36

IV. Long Win Products of Heat Transfer Research Equipments for Electronic Package and Components.

1. Thermal conduction:

- A. Package material
  - Rjc measurement — LW-9150
  - Rja measurement — LW-9151
- B. Heat dissipation material
  - Metal
    - material, composition
    - heat treatment
  - Non-metal
    - carbon
    - semi-conductor material, leading heat dissipation mechanism
- C. Interface material
  - Liquid state
  - Solid state
  - Phase variation
  - Combined Material
  - (all of the above) — 9021

- D. Interface relationship
  - Surface Coarseness — 3-dimension microscope
  - Load Pressure
    - shape-changing material
    - Non-shape-changing material
- E. Phase-change component
  - Heat pipe Cooler
    - Heat Pipe—9130
    - Vapor Chamber
    - Micro Vapor Chamber
    - Flat Plate Heat Pipe

2. Air Convection of Thermal Conduction

A. Natural Convection
- temperature chamber without wind — LW-9022
- controlled low speed of wind field chamber — LW-9144

B. Forced Convection

- air flow rate status — LW-9015、9014
- air velocity status — LW-9016、9300T、6200T、9032
- turbulence status — LW-9016、9300T、6200T、9093
- air velocity and surface relationship — LW-9093
- fan characteristics
  - blade — LW-9014、9015、9081、9089、9120、9125
  - fan shape
  - gap ratio
- electricity and magnetic property — LW-9123
- bearing property and life
- noise — LW-9099
- vibration measurement — LW-9154
- torque measurement — LW-9153
- inspection and calibration on production line — LW-2333N

C. Flow Visualization

- in the air
  - 2-D wind tunnel － LW-9016、9300T、6200T
  - 3-D smoke tunnel － LW-9133
- in the water
  - 2-D water tunnel － LW-9093、2330、9065
  - 3-D water tank － LW-9134
  - general visualization water tank － LW-2356
- model

Similarity Relationship between in the Air and Water:

Similar Conditions in the Fluid Mechanics as following:

a. Geometrically Similar

b. Kinematic Similarity

c. Dynamically Similar

a. Geometrically Similar: while the ratio of corresponding length between the real element and model is constant

$$\frac{l_p}{l_m} = C_l = \text{const.}$$

b. Kinematic Similar: while two corresponding points of real element and model take kinematically similar motion within proportional time, the corresponding speed and acceleration distribution status is similar; that is

Time Ratio: $$\frac{t_p}{t_m} = C_t = \text{const.}$$

Speed Ratio:
$$l_p = \upsilon_p t_p$$
$$l_m = \upsilon_m t_m$$
$$\frac{\upsilon_p}{\upsilon_m} = \frac{\frac{l_p}{t_p}}{\frac{l_m}{t_m}} = \frac{C_l}{C_t} = \text{const.}$$

Acceleration Ratio: $$\frac{\alpha_P}{\alpha_m} = \frac{\frac{\upsilon_p}{t_p}}{\frac{\upsilon_m}{\upsilon_m}} = \frac{C_l}{C_t^2}$$

c. 動力學相似(Dynamically Similar) ：實物與模型相對應的兩點，在力學上表示相似的力分佈狀態，作用於流體的物體之力與慣性力相對應

$$C_{\rho} = \frac{\rho_p}{\rho_m}$$

$$\frac{D_p}{D_m} = \frac{m_p \alpha_p}{m_m \alpha_m} = \frac{C_{\rho} C_l^4}{C_t^2} = \text{const.}$$

Reynold's Similarity:

$$Re = \frac{D \times U}{\nu} = \frac{D \times U}{\frac{\mu}{r}}$$

Re: Reynold's number

D: model dimension

U: fluid velocity

ν : fluid dynamic coefficient of viscosity

μ : fluid viscosity

r : fluid specific gravity

3. Radiant thermal conduction

A. Surface coating
- heat-absorbing
- heat-cooling
- anti-corrosion
- adhesion

B. Surface treatment inspection

4. Related physical property calibration and measurement

- **A. Temperature**
  - Measurement — LW-9046
  - Calibration — LW-9049
  - Data acquisition — LW-9139
  - visualization — LW-9119
- **B. Air flow rate**
  - Measurement — LW-9014, 9015, 9081, 9089, 9120, 9125
  - Calibration
  - Data acquisition
- **C. Air velocity**
  - Measurement — LW-9032, 9300, 9069, 9016, 9300T, 6200T
  - Calibration — LW-9037
  - Data acquisition

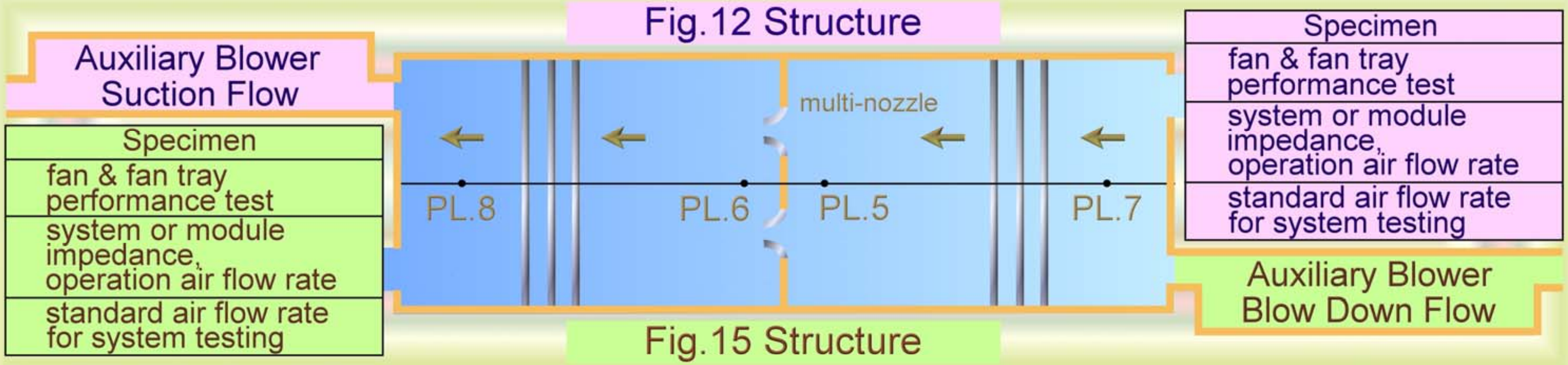
- D. Force
  - Measurement — LW-9052
  - Calibration
  - Data acquisition
- E. Pressure
  - Measurement
  - Calibration
  - Data acquisition
- F. Noice
  - Measurement — LW-9099
  - Calibration
  - Data acquisition
- G. Thermal Resistance — Components — 9053，9052 / 9091 / 9092 / 2333N

5. Environmental and Life Test

1. Thermal Cycling Test
2. Thermal Shock Test
3. Temperature and Humidity Test
4. Altitude test--9145
5. Shock Test--9059
6. Vibration Test
7. Age and Life Test

LW-Series Air Flow Rate & Pressure Measurement Apparatus

Meeting AMCA 210-99 Standard
Including Fig.12 & Fig.15 Structure
design & manufacturer : Long Win Science & Technology Corporation
Web site : http://www.longwin.com
Tel : 886-3-464-3221
Fax : 886-3-496-1307



Features

- fan performance, PQ curve,blade design, electric function
- system & module impedance
- offer operation air flow rate set up T-Q / R-Q chart

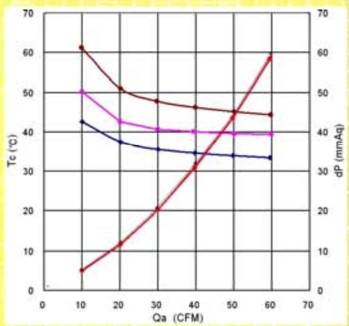
Measurement Item

- air flow rate : series 2.4 ~ 3000 CFM
- accuracy : 1 ~ 3.5% INFS full scale of indicated nozzle
- I , V , rpm of Fan

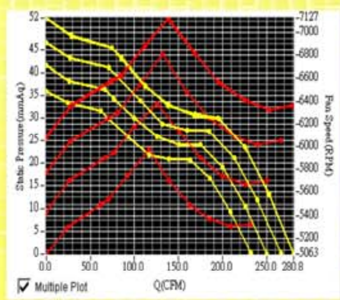
Air Flow Rate Calculation

$Q = Cd \cdot \Sigma A \cdot U$
Q : air flow rate
ΣA : nozzle area
Cd : discharge coefficient
$1/2\rho U^2 = \Delta P = P_{56}$
$\rho_{air} = f(Td, Tw, Tc, P_{PL.5})$
$Cd = f(Re)$
$Re = f(D, U, \mu, \rho)$

RQ Chart



PQ Chart



LW-9081 Wind Tunnel　　　air flow rate : 2.4 – 60 cfm

LW-9015 Wind Tunnel & Rear Additional Thermal Wind Tunnel

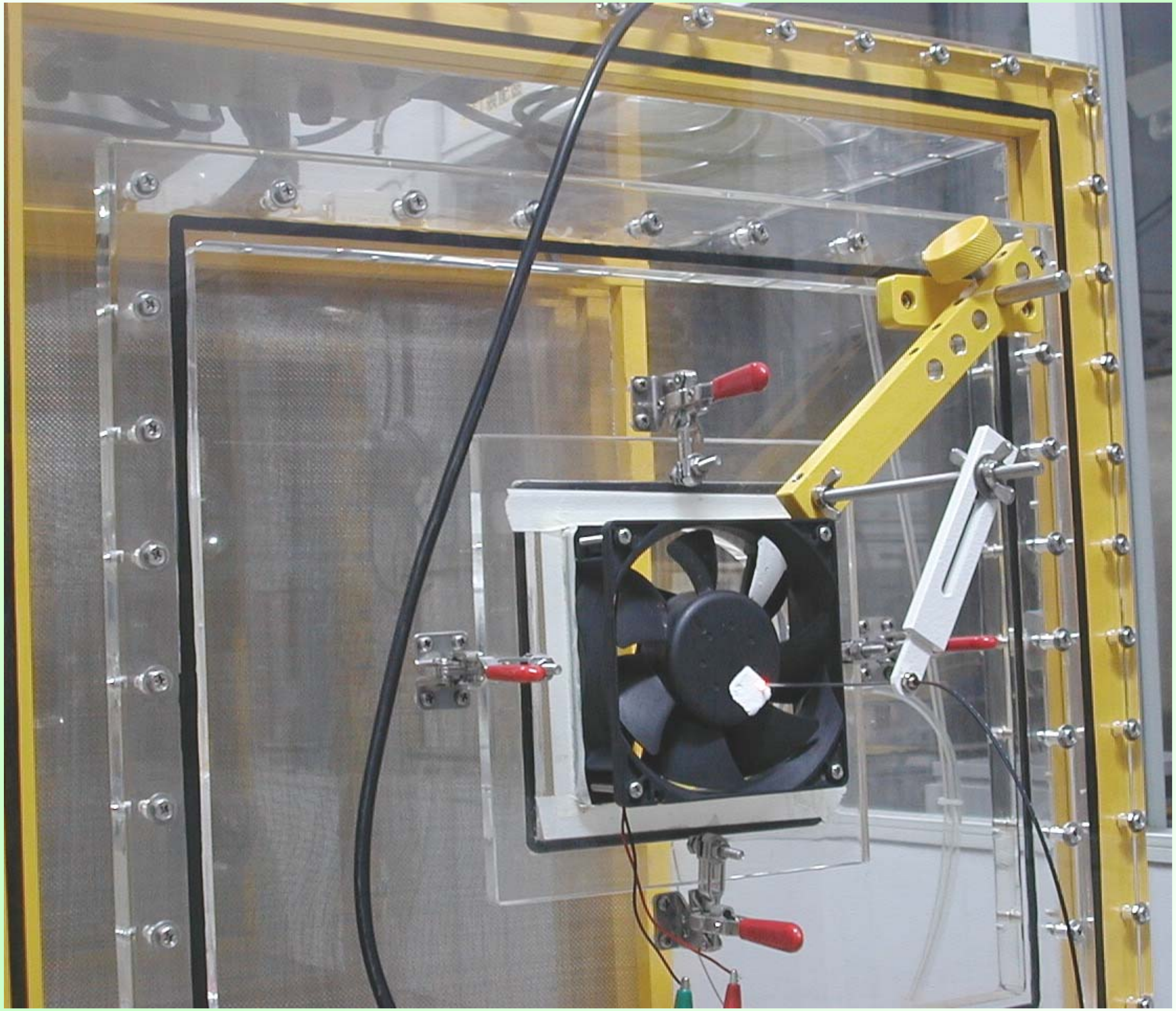
Air flow rate : 2.4 – 250 cfm

LW- 9089 Wind Tunnel air flow rate : 20 – 800 cfm

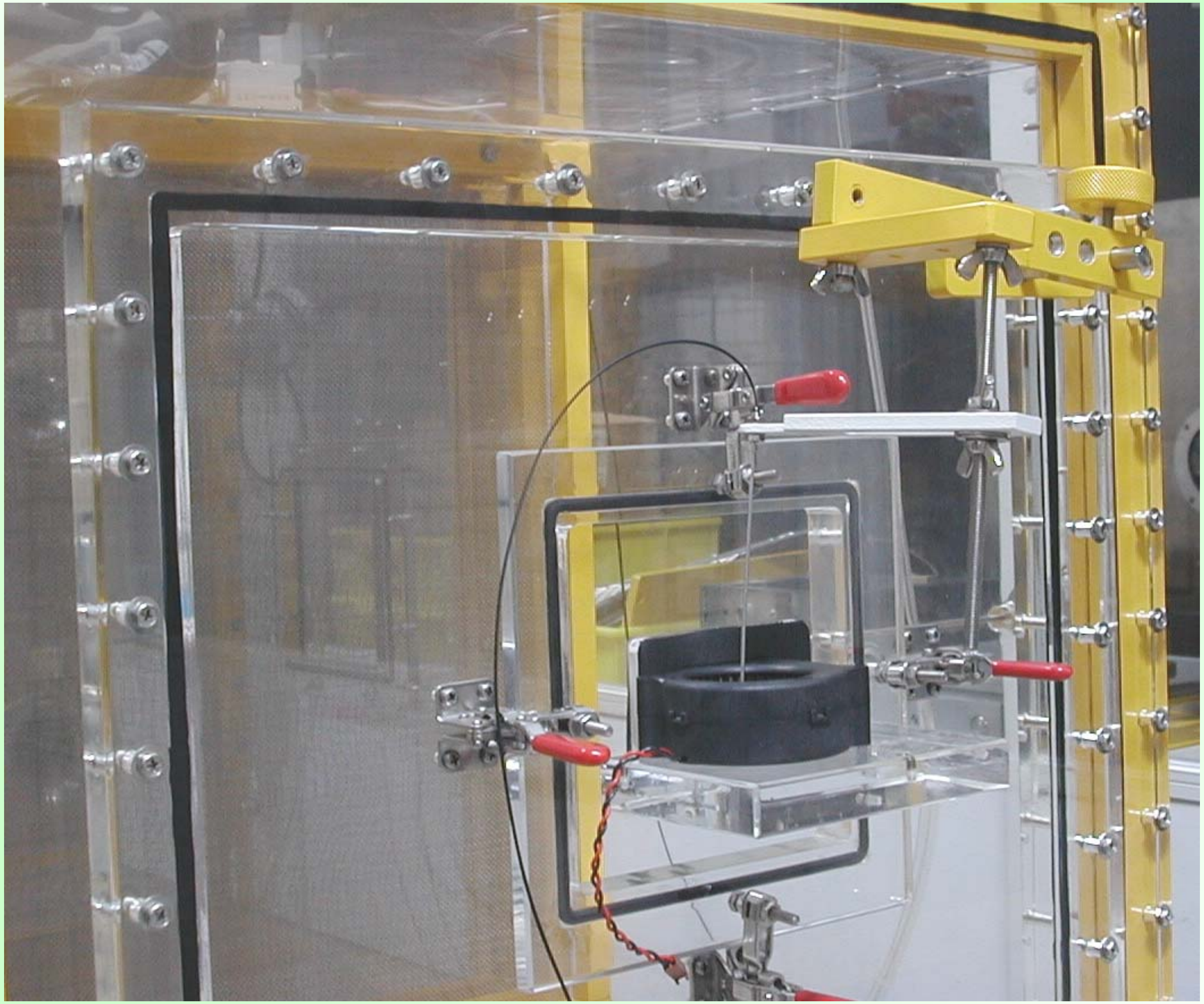
LW-9120 Wind Tunnel　　air flow rate : 30 – 1000 cfm

LW-9125 Wind Tunnel air flow rate : 50 – 3000 cfm

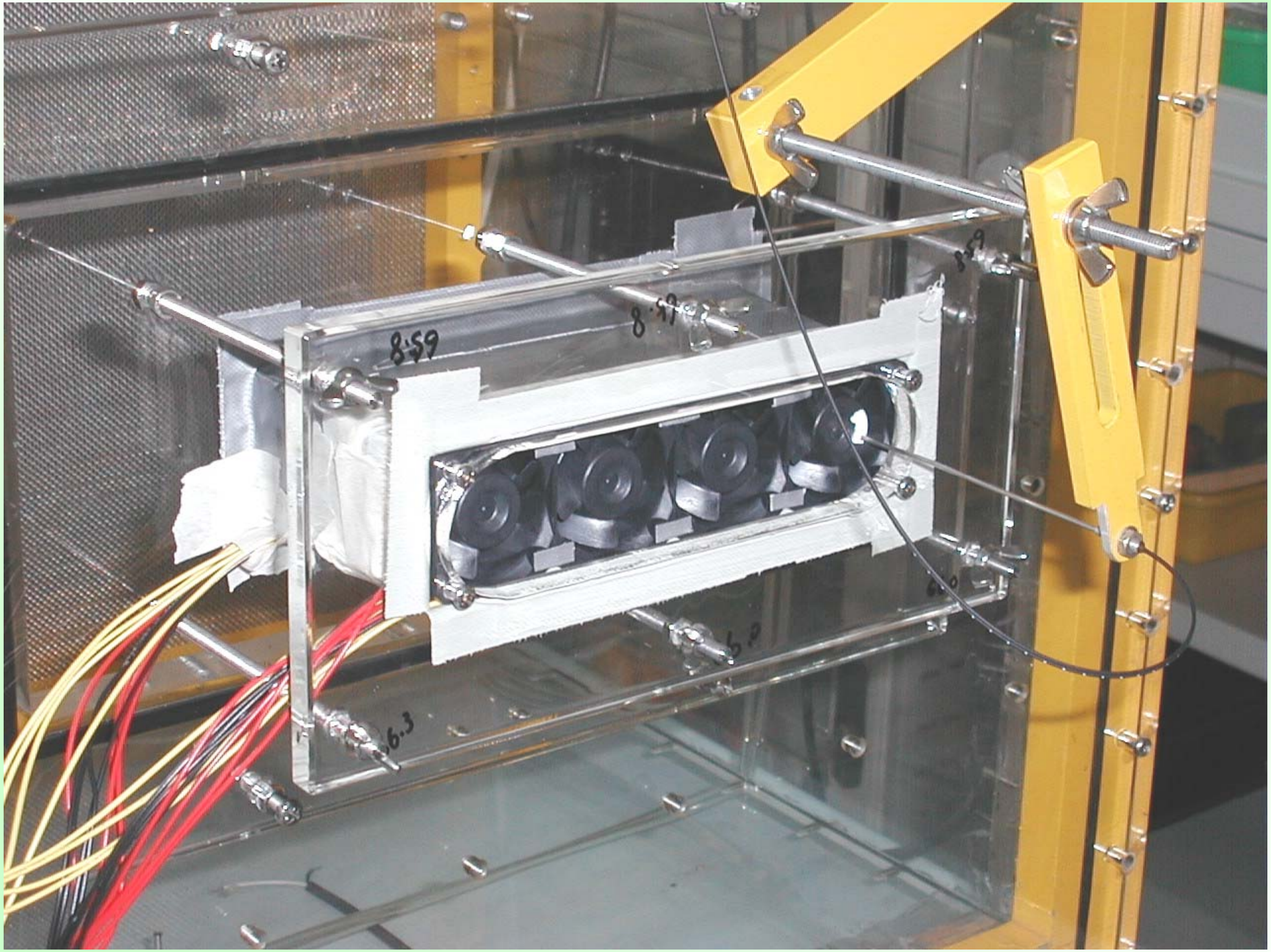
axial fan test



blower test



fan tray test



module test : impedance & Qop

module test : impedance & Qop